We and trees of our city – some perspectives on ecosystem „services“ and tree vitality

Karlsruhe palace, part of the city and palace garden

Photo: Sebastian Mang, KIT

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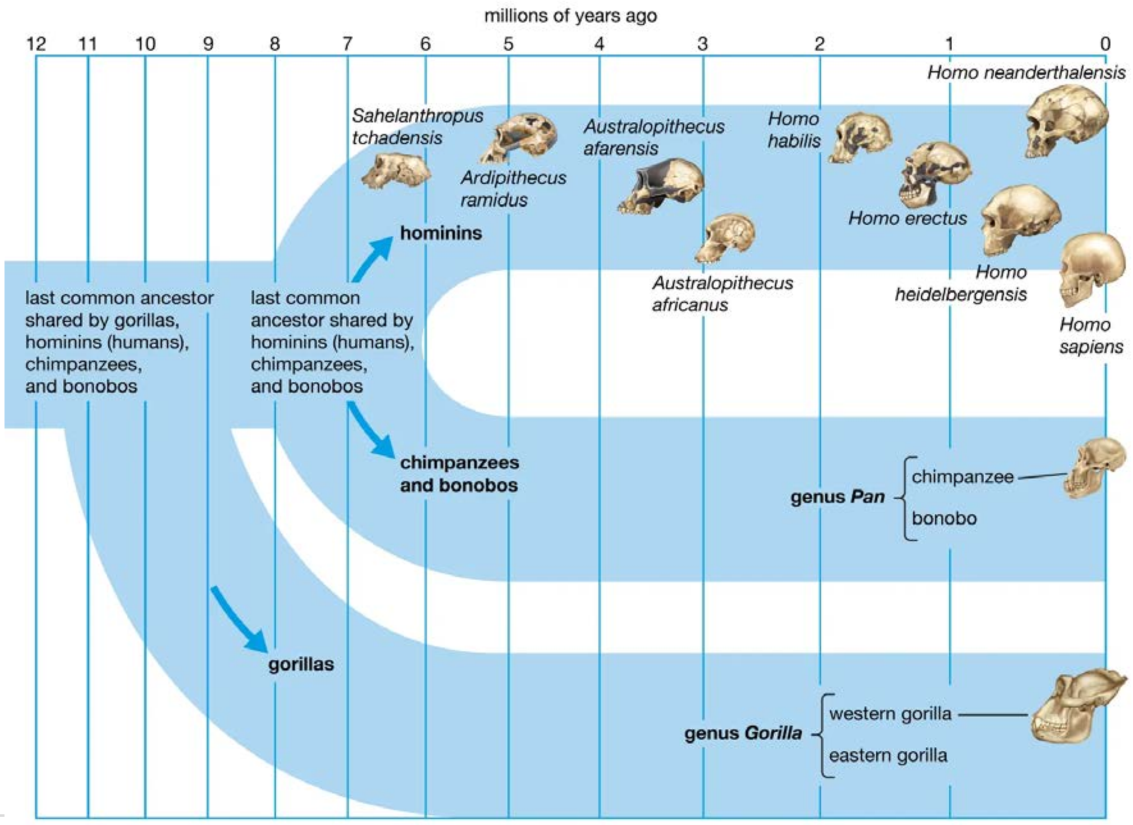
Since when we know trees?

- We speciated as human ca. 200,000 years ago and we know trees since then because trees gave us first shelter and food
- We always followed green patches: forests and savanna



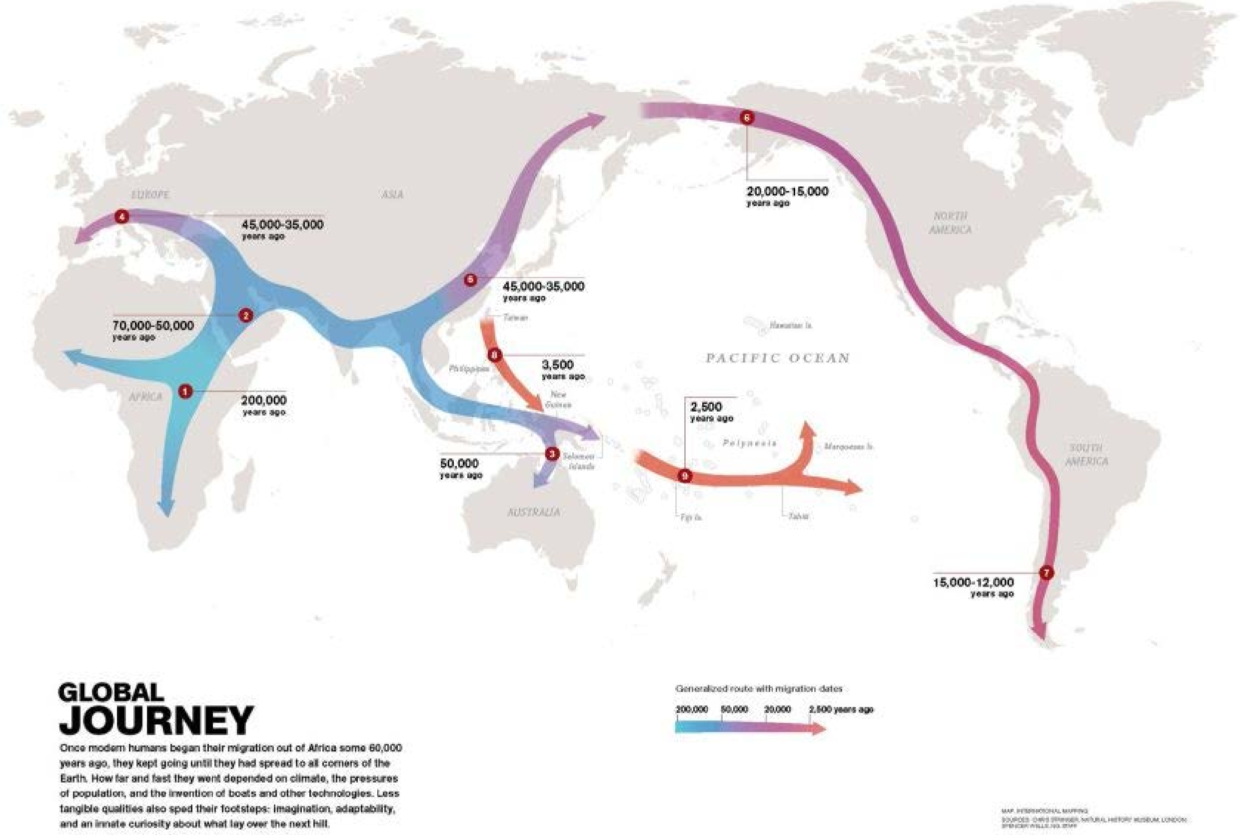


Photo source: Encyclopedia Britannica, National Geographic Society

Since when we have started living in cities?

- Some of our ancient ancestors had become urbanites ca. 5000 years ago

City of Mohenjo-daro
population ca. 40,000;
in 3000 BCE
Indus Valley Civilization

City of Babylon
population ca. 200,000
in 2000 BCE
Sumerian Civilization

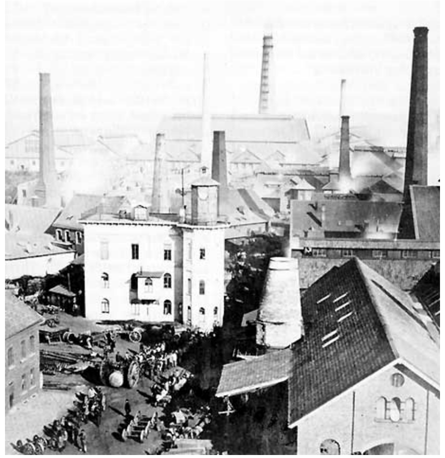
City of Athens
population 140,000
in 500 BCE
Greek Civilization

Photo source: Wikimedia Commons

Industrial revolution and colonial cities

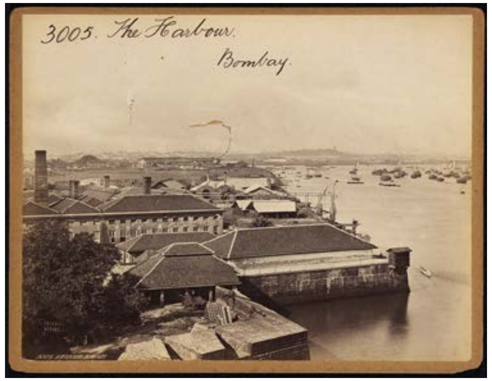
- Some of our recent ancestors lived through rapid urbanization due to colonialization and industrial revolution 18th and 19th century

Manchester



Essen

New Orleans



Bombay/Mumbai

Calcutta/Kolkata

Photo source: Wikimedia Commons

What is the future?

- 67% of 9.7 billion people will live in cities by 2050 (UN)

Tokyo

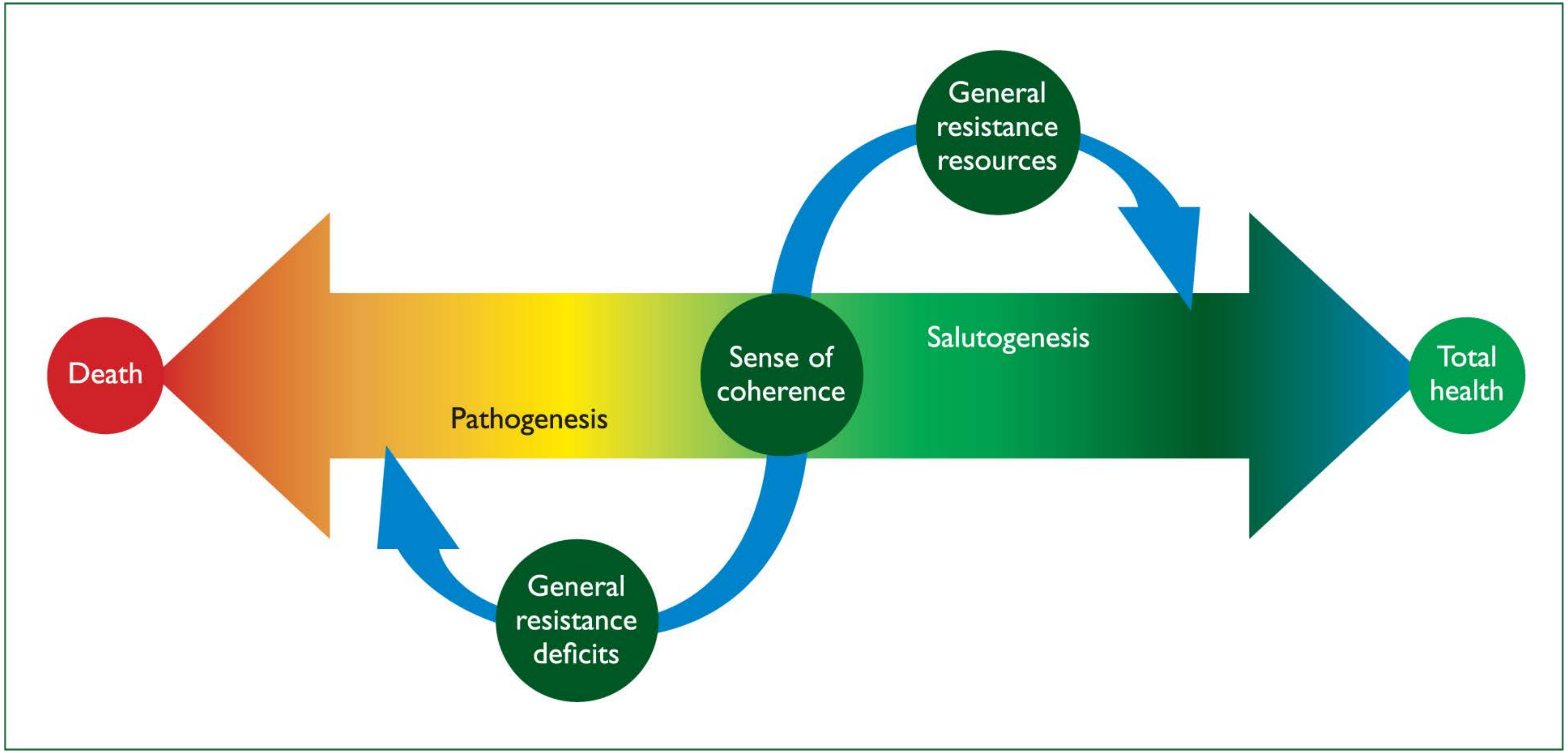
Photo source: Pixabay

- We spent only 2% of our time since we created our first cities which were still surrounded by green lands

- We spent only 0.1% of our time since we started living in gray cities without enough green space

A removal of trees from our sight can negatively influence us because we as a social animal evolved with trees for most of our time in this planet (Biophilia hypothesis)

Pathogenesis vs. Salutogenesis



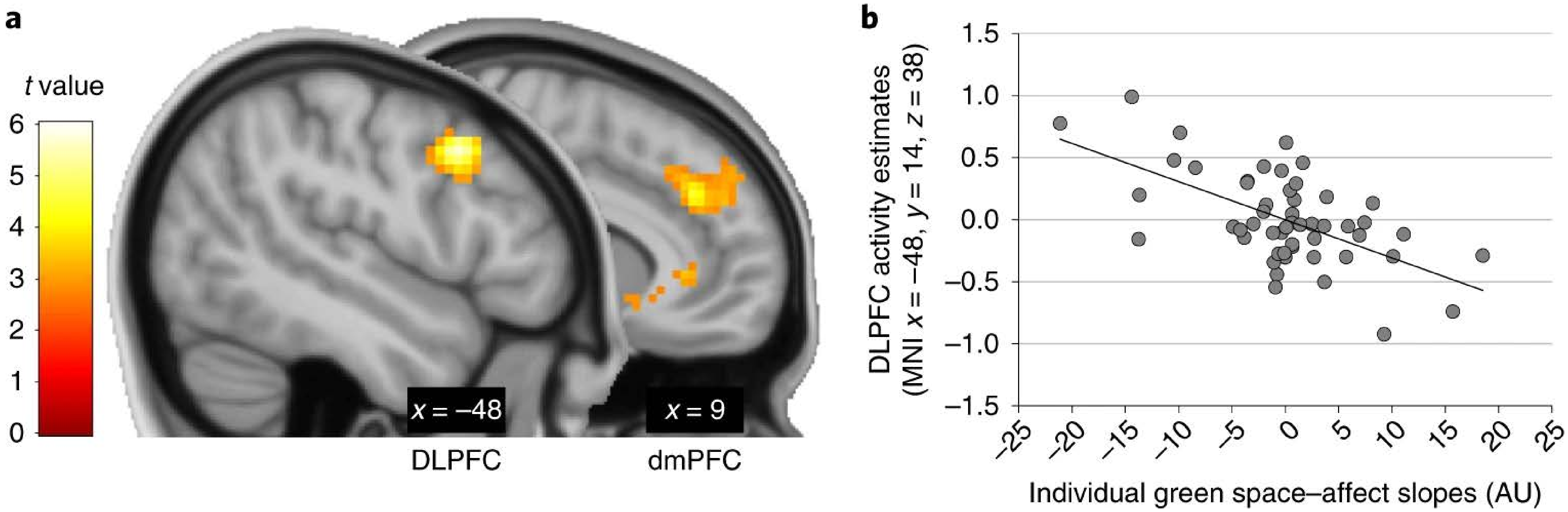
Antonovsky, Aaron "Health, Stress and Coping" San Francisco: Jossey-Bass Publishers, 1979

Graphic source: Krista Cockrell

Trees and forests act as Salutogenic source

- Green spaces act as a source of inspiration (visual cue, olfactory cue, sensory cue)
- Exposing ourselves to nature releive us from daily life stress
- Spending time in nature improve human wellbeing: physical health and mental health
- Above claims are corroborated by many articles in human psychology, behavioral science, social science, environmental psychology and forest science
- But biological underpinnings of above observations were unknown

When we spent time in urban green space then activities in prefrontal cortex declines, hence, reduce aversive emotion possession: increase psychological well-being



First neurological/biological evidence on how trees influence our brain

nature neuroscience | BRIEF COMMUNICATION
https://doi.org/10.1038/s41593-019-0451-y

Neural correlates of individual differences in affective benefit of real-life urban green space exposure

Heike Tost[1,5*], Markus Reichert[1,2,5], Urs Braun[1,5], Iris Reinhard[3], Robin Peters[4], Sven Lautenbach[4], Andreas Hoell[1], Emanuel Schwarz[1], Ulrich Ebner-Priemer[2,5], Alexander Zipf[4,5] and Andreas Meyer-Lindenberg[1,5*]

So we need trees and they do not need us

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This conviction motivated us to develop a project 4 years ago called GrüneLunge or GreenLung

In that project we aimed to develop strategies for increasing resilience of urban and peri-urban forests to climate change impacts in Karlsruhe so that we can preserve our exisiting forests and even increase future forest cover

https://www.projekt-gruenelunge.de/

GrüneLunge

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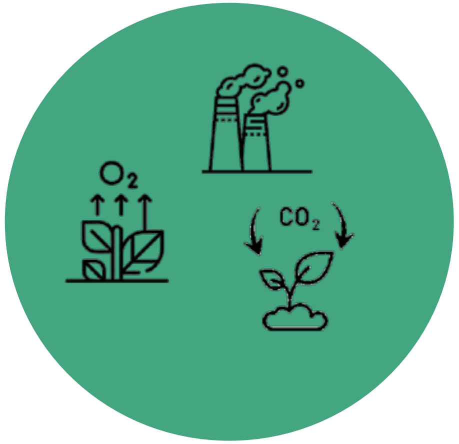
Ecosystem services from urban forests

Provisioning

- Timber
- Biomass
- Fruits



Regulating

- Air quality improvement
- CO2-uptake and storage
- Flood and erosion control

Supporting

- Biodiversity: Habitat for flora and fauna

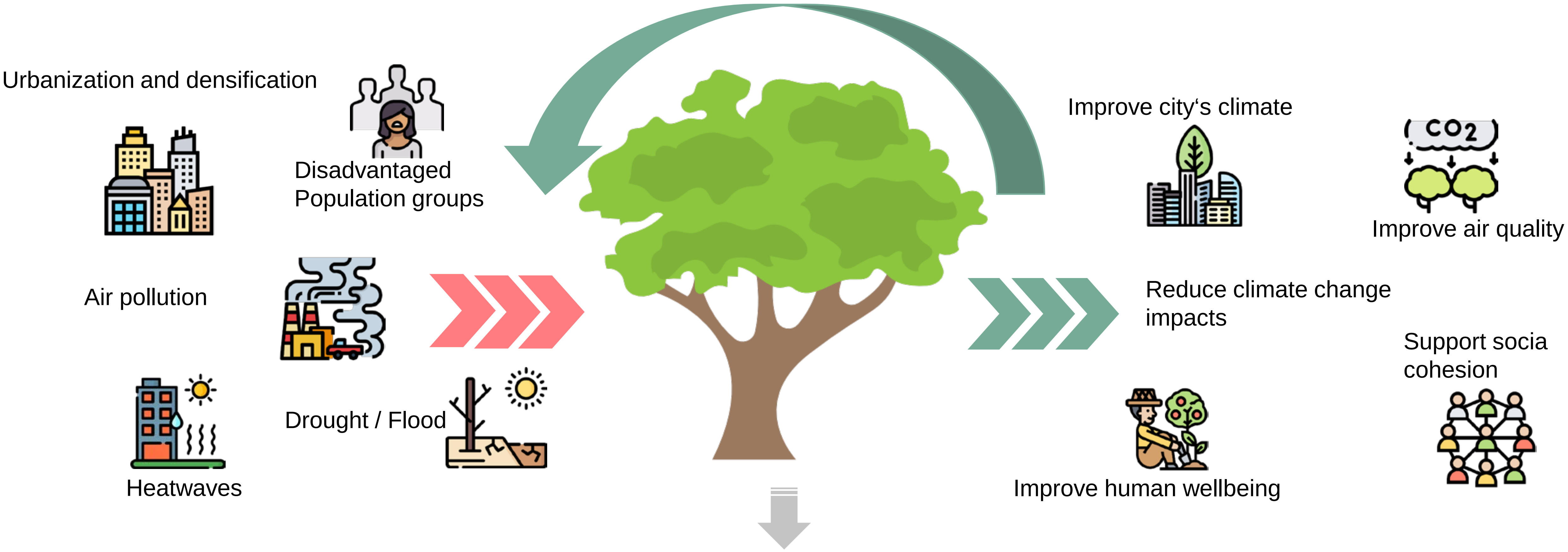
Cultural

- Nature exposure for citizens
- Wellbeing and health

Disservice

- Allergy

Challenges of a tree in a city



Tree as a Green Lung of a city

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Definition and types of urban forest

“**Urban forests** can be defined as networks or systems comprising all woodlands, groups of trees, and individual trees located in urban and peri-urban areas; they include, therefore, forests, street trees, trees in parks and gardens, and trees in derelict corners.” (the FAO of UN)

Urban forests can be classified into 11 main types based on their structure (only considering trees growing on ground and not in/on buildings)

Street trees

Kaiserstraße, Karlsruhe
(photo: BNN)

Champs-Élysées, Paris
(photo: Wikipedia)

Red road, Calcutta
(photo: Wikipedia)

Landscape boulevards

Boulevard in Suzhou, China
(photo: JPW.com.au)

Ballerup boulevard, Danemark
(source: Marianne Levinsen Landskab)

Greenways

Car free cycle and foot-paths, North Minneapolis Greenway, USA
(source: http://thealliancetc.org/)

Furture Greenways in Vancouver
(source: Vancouver City)

Urban parks

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Karlsruhe Castle Park
(photo: BNN)

BerlinTiergarten park
(photo:Shutterstock)

Victoria Park, Calcutta, India
(photo:Times of India)

Gardens

Courtyard hourse gardens
(photo: House and Garden, UK)

Permaculture kitchen garden
(photo: freepermaculture.com)

Trees for conservation, education and display

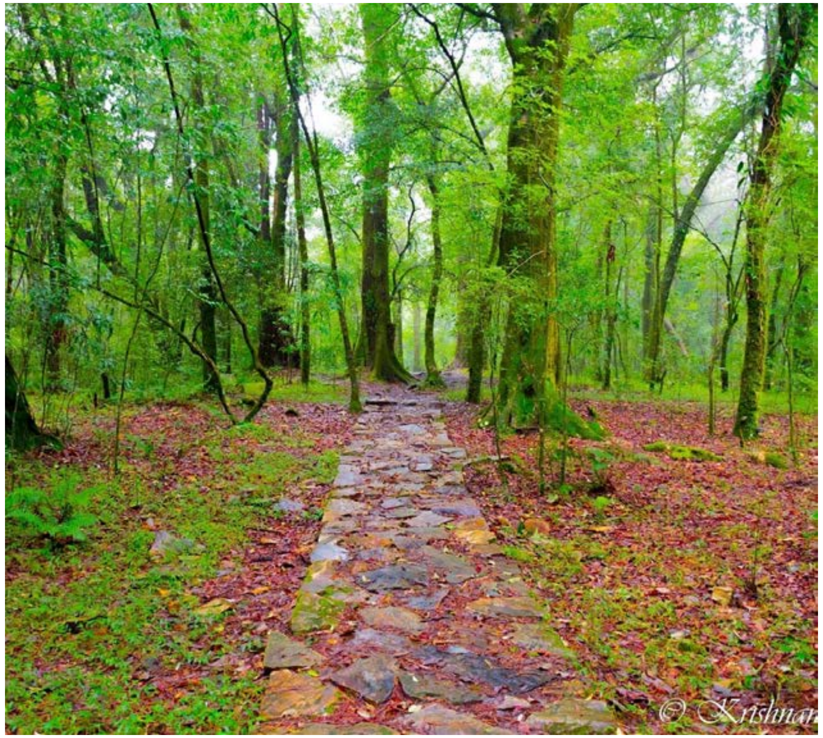
Botanical garden (Kew, London)
(photo: BBC)

Arboretum, Baden-Baden
(photo: SWR)

Zoological garden, Karlsruhe
(photo: Zoo Karlsruhe)

Religious/sacred urban forests

Karlsruhe cemetery trees
(photo: Freizeitclub Karlsruhe)



Sacred forests in Shillong city, India
(photo: P Krishnan)

Urban/peri-urban woodlands

Grünewald, Berlin
(source: Wikimedia commons)

Aare forests, Mumbai
(source:Llyod Law College)

Hardtwald forest, Karlsruhe
(source: MainKA)

Coastal and river promenade, river trail

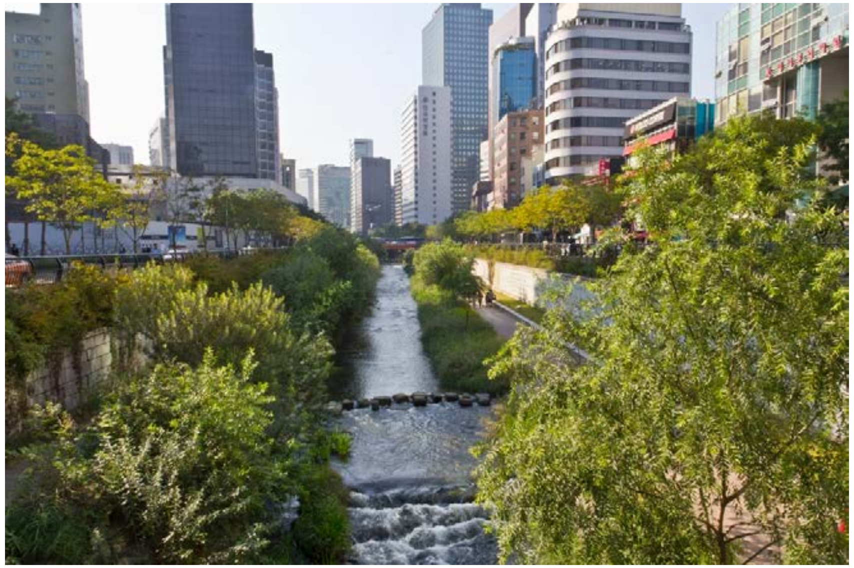
River promenade of Cologne
(photo: Dreamstime)

A bike trail along river in Karlsruhe
(photo: Alltrails)

Coastal promenade in Durban
(photo: Tripadvisor)

Wetland and riparian urban forests

London wetland urban forest
(photo: WWF)



Seoul riparian urban forest
(photo: Kaizer Rangwala,
Flickr Creative Commons)

Philadelphia riparian forest buffers
(photo: Randy Calderone,
Philadelphia Water Department)

River corridors „sponge city/Schwammstadt“

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Puyangjiang River Corridor, Pujiang County, Zhejiang, China
(source: Turenscape)

Qnuli stormwater park, China
(source: Turenscape)

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Urban forest inventory

Who are responsible for urban trees?

Tree „inspection“ for ensuring public and vehicle safety

Urban forest inventory

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List of all trees by the large owners (Tree Cadastre or *Baumkataster*)

High variation of methods and variables in Tree Cadastre (lack of analysis capacity)

i-tree-eco approach of urban forest inventory

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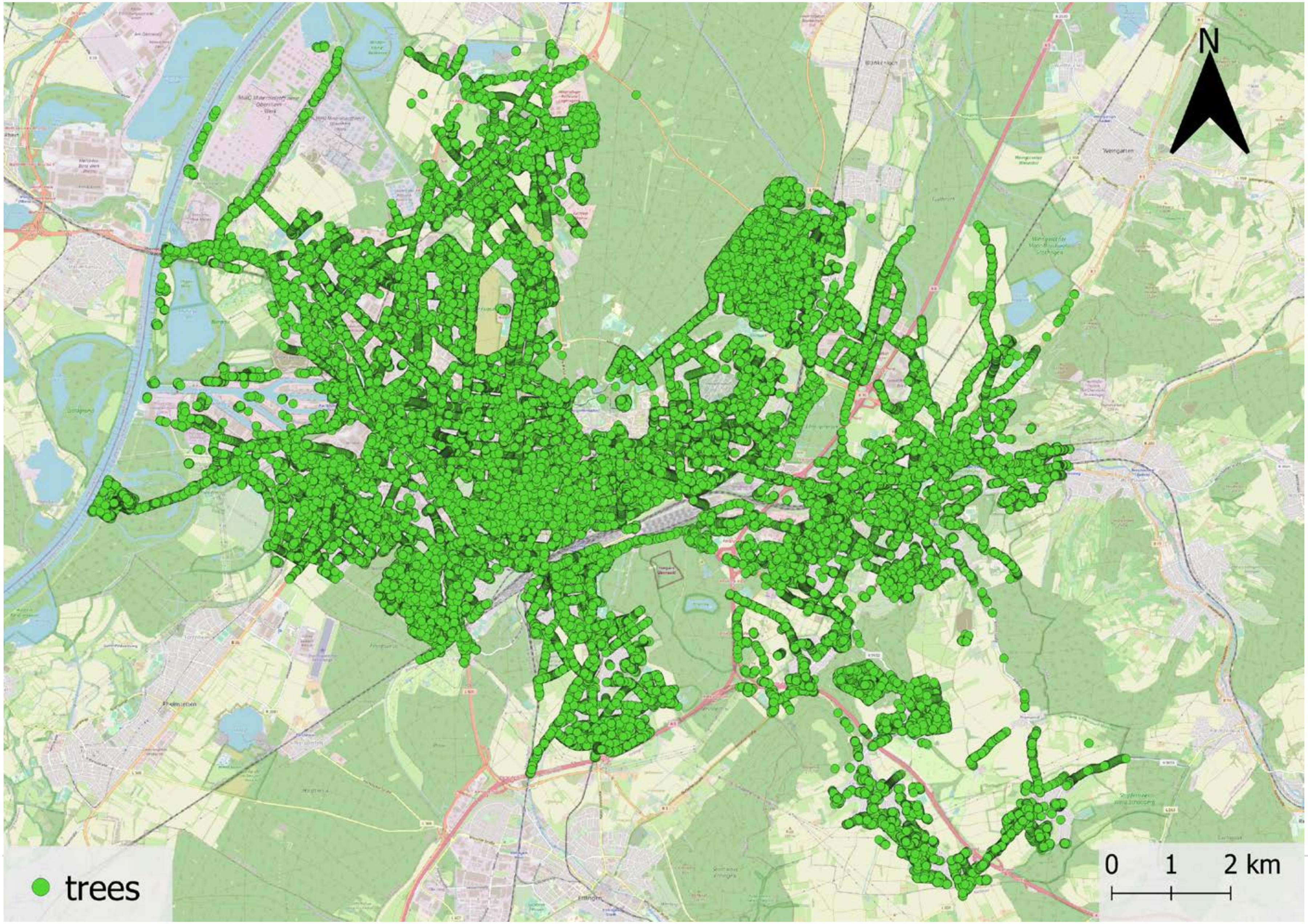
Tree cadaster of the City of Karlsruhe



Common data

Species
Height (estimate)
DBH (in class)
Crown damage class
Location information

How many plots are needed for an urban forest inventory?

After 200 plots relative standard error of total number of tree fall less than 12%

After 400 plots relative standard error of total number tree was 9%

For region around 20000 ha minimum 200 Plots, is therefore, necessary

A Ground-Based Method of Assessing Urban Forest Structure and Ecosystem Services

David J. Nowak, Daniel E. Crane, Jack C. Stevens, Robert E. Hoehn, Jeffrey T. Walton, and Jerry Bond

Effect of Plot and Sample Size on Timing and Precision of Urban Forest Assessments

David J. Nowak, Jeffrey T. Walton, Jack C. Stevens, Daniel E. Crane, and Robert E. Hoehn

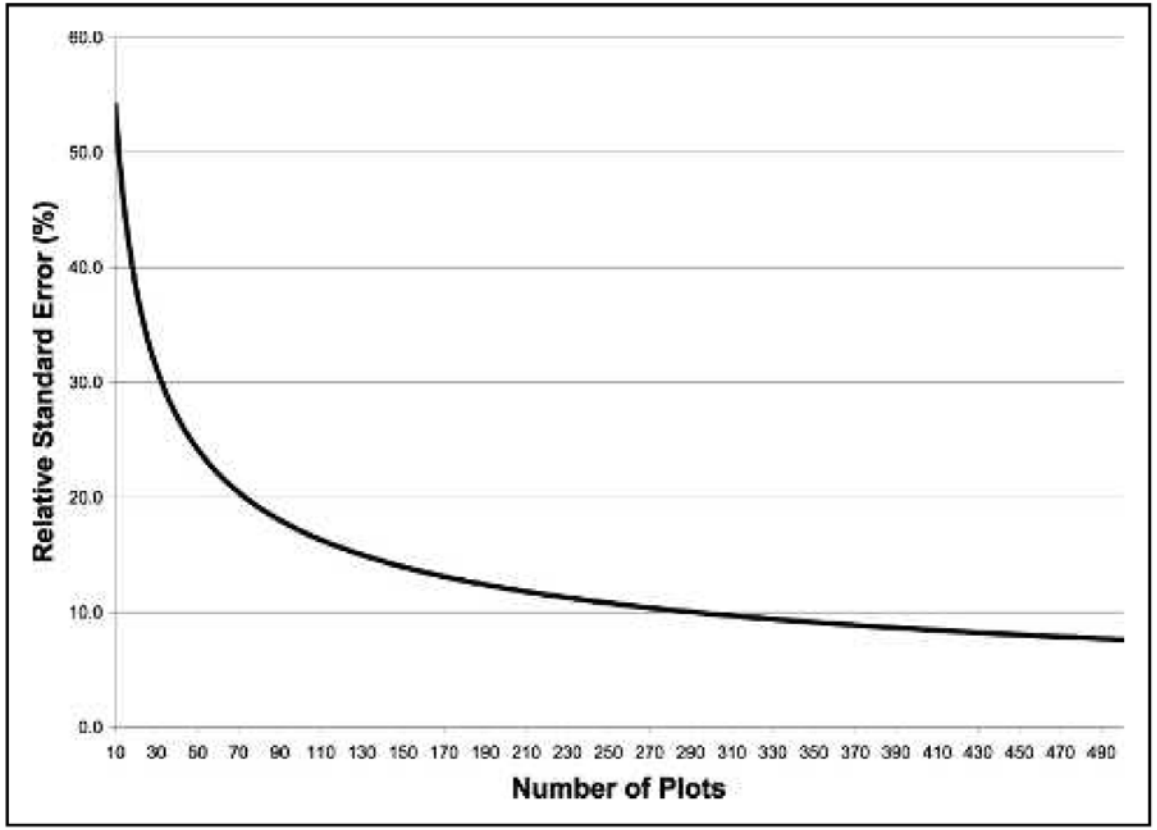
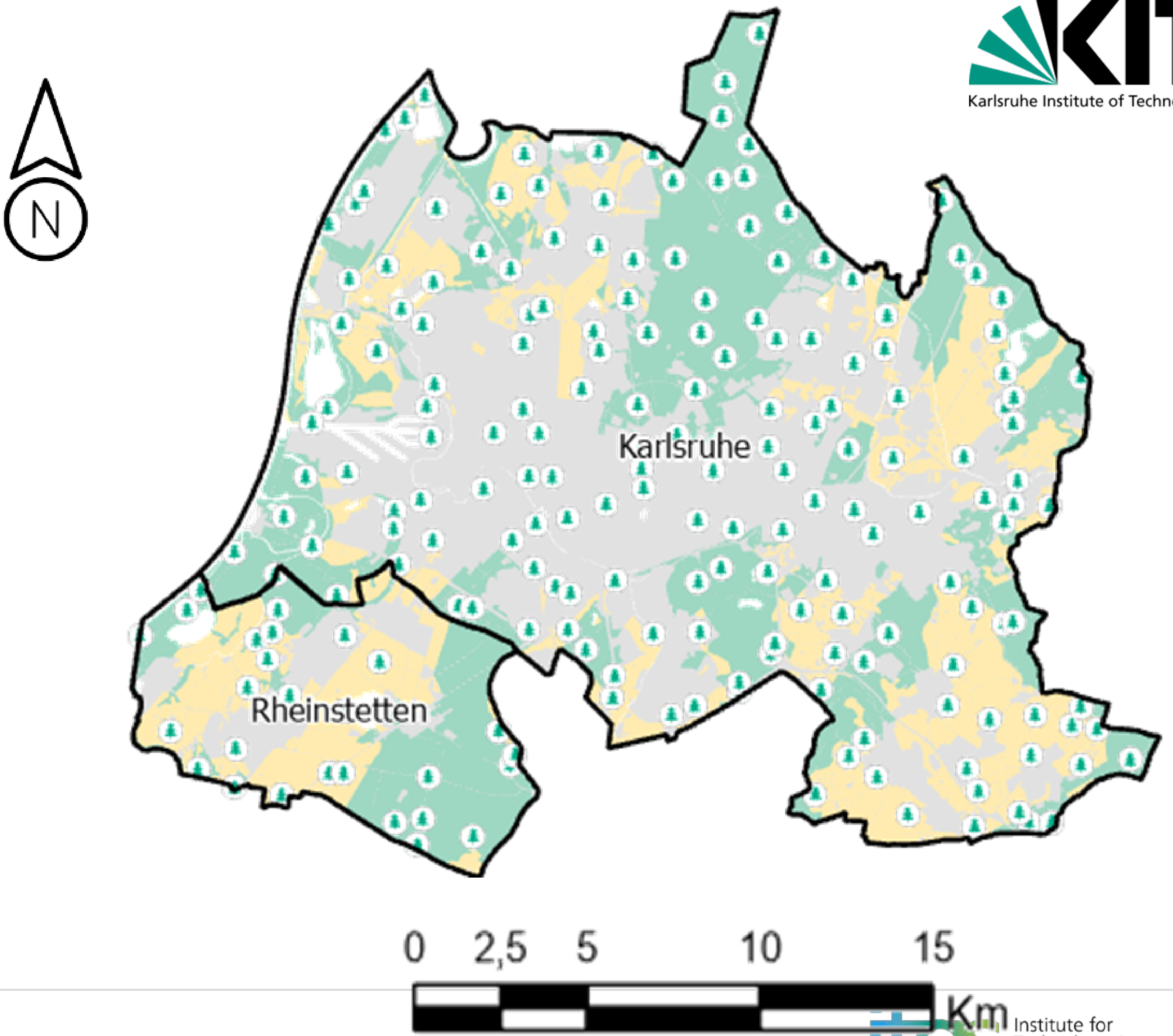


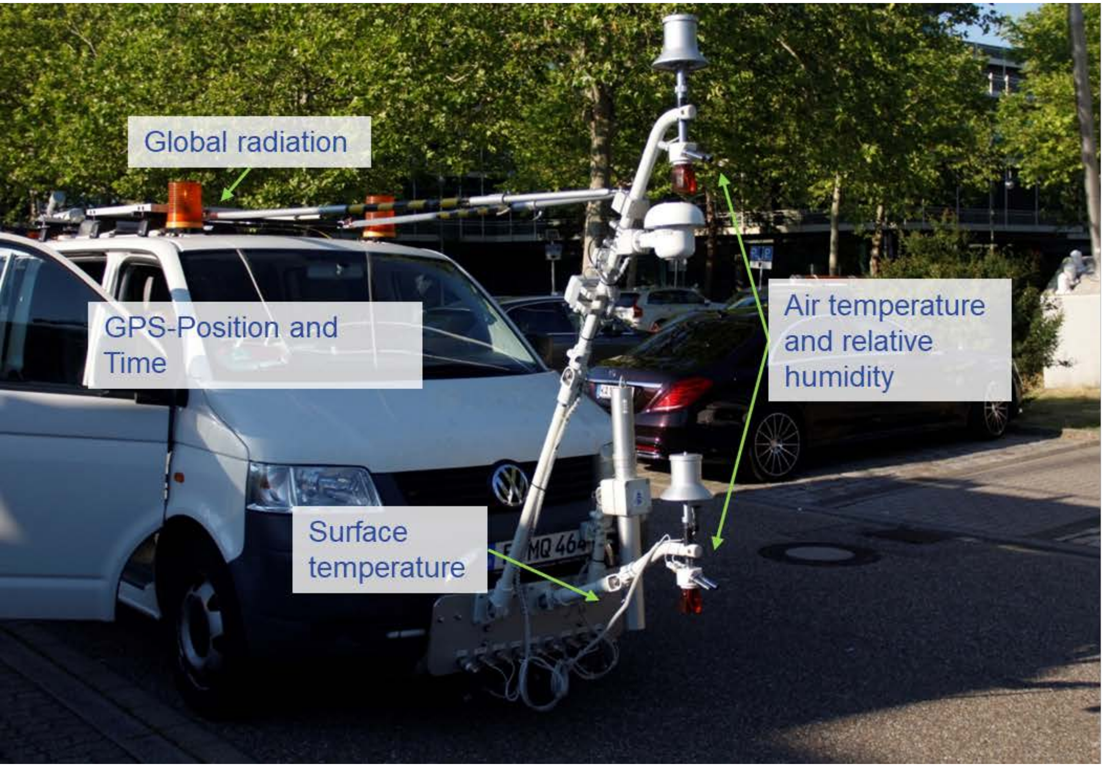
Figure 1. Estimated relative standard error (SE/total × 100) of total number of trees based on varying number of total one-tenth acre (0.04 ha) field plots.

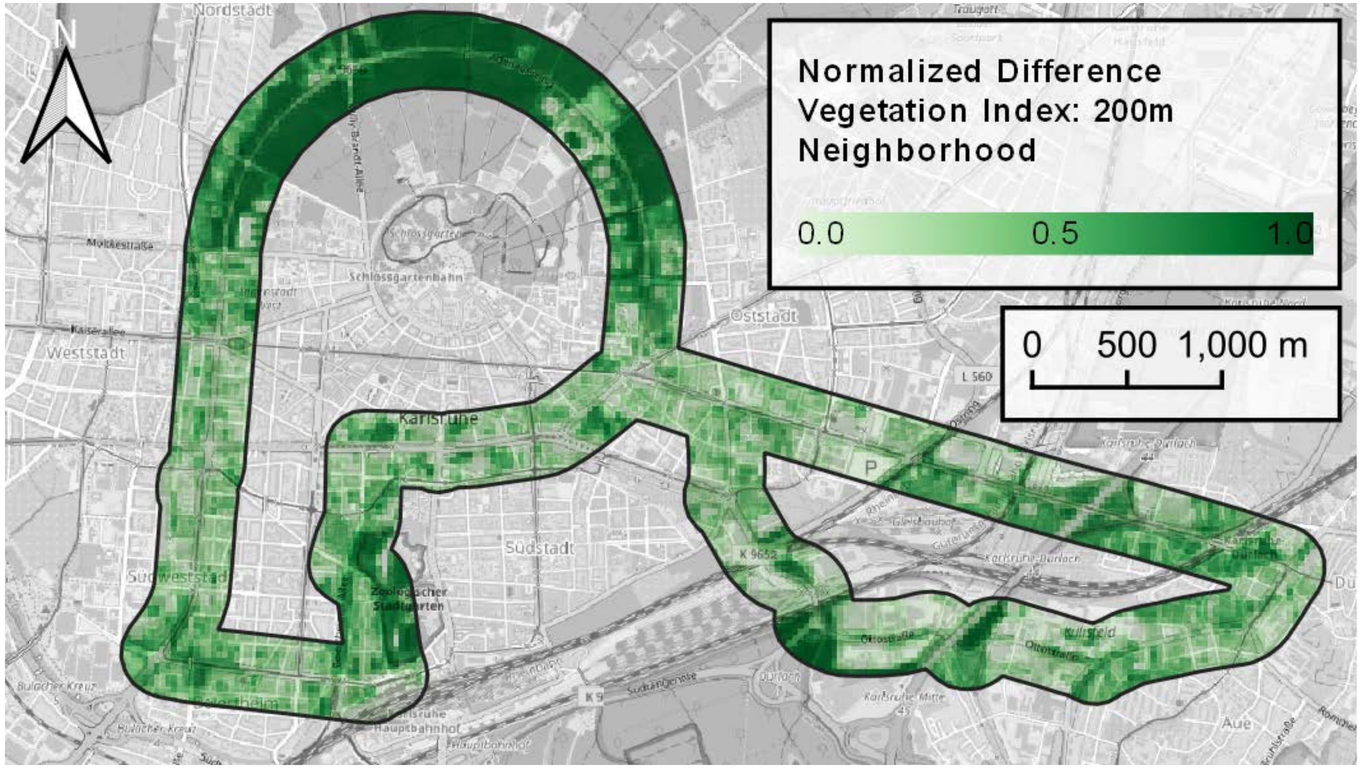
Plot-based urban forest inventory in Karlsruhe and Rheinstetten



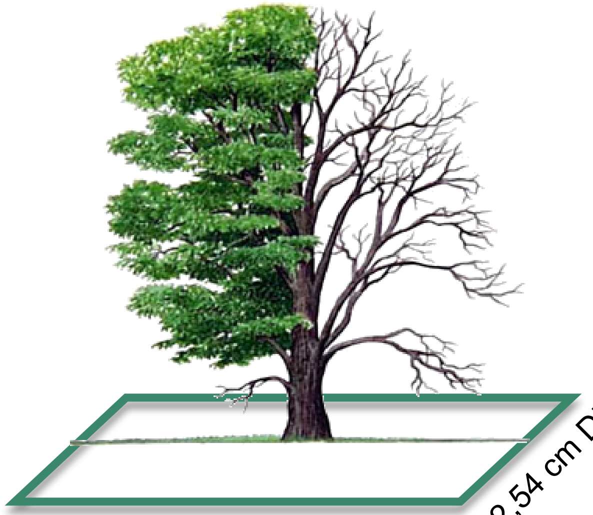
201 random Plots in ca. 20000 ha areas

Urban microclimate and scope of tree cover in temperature reduction





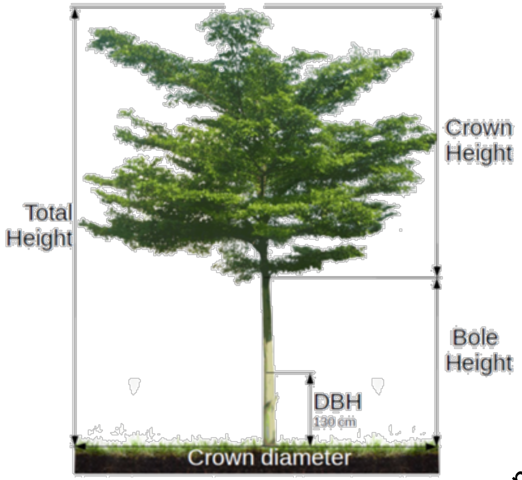
What can be measured during inventory?



>2,54 cm DBH

Tree stress symptoms
Crown dieback
Missing crown
Defoliation
Discoloration

2968 Trees



>2,54 cm DBH

Tree species
Tree height
Tree diameter
Crown width

105 Species

Microhabitat

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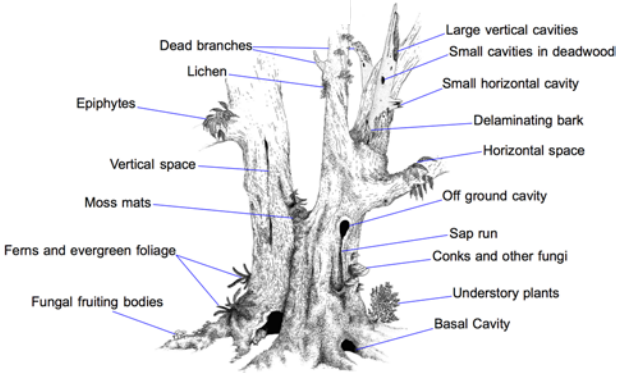

>20 cm DBH

Cavities
Nests
Moss and lichens
Dendrotelms
Many more
(used European Forest Institute‘s microhabitat field guide)

Tree sketches: Root Problems (2021); NFA Forest Wiki (2020); Arboriculture International (2021) and TCV Scotland (2017)

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Ecosystem services assessed from 2968 trees (201 plots)

Provisioning ecosystem services	Unit
Leaf biomass	kg/ha
CO_2 storage	kg/year
Non-timber forest products • Edibility • Medicinal uses • Decorative uses • Other uses	Number

Supporting ecosystem services	Unit
Microhabitat abundance	Number
Microhabitat richness	Anzahl
Tree species diversity	Shannon index
Tree size diversity	Gini index

Regulierende ÖSL	Einheit
Oxygen production	kg/year
CO_2 sequestration	kg/year
Hydrological benefits • Potencial evapotranspiration • Evapotranspiration • Transpiration • Water intererception • Avoiding surface runoff	m^3/year
VOCs Emissions • Isoprene • Monoterpene	g/year
Pollution removal • Ozone (O_3) • Nitrogen di-oxide (NO_2) • Sulphur dioxide (SO_2) • PM2.5	g/year

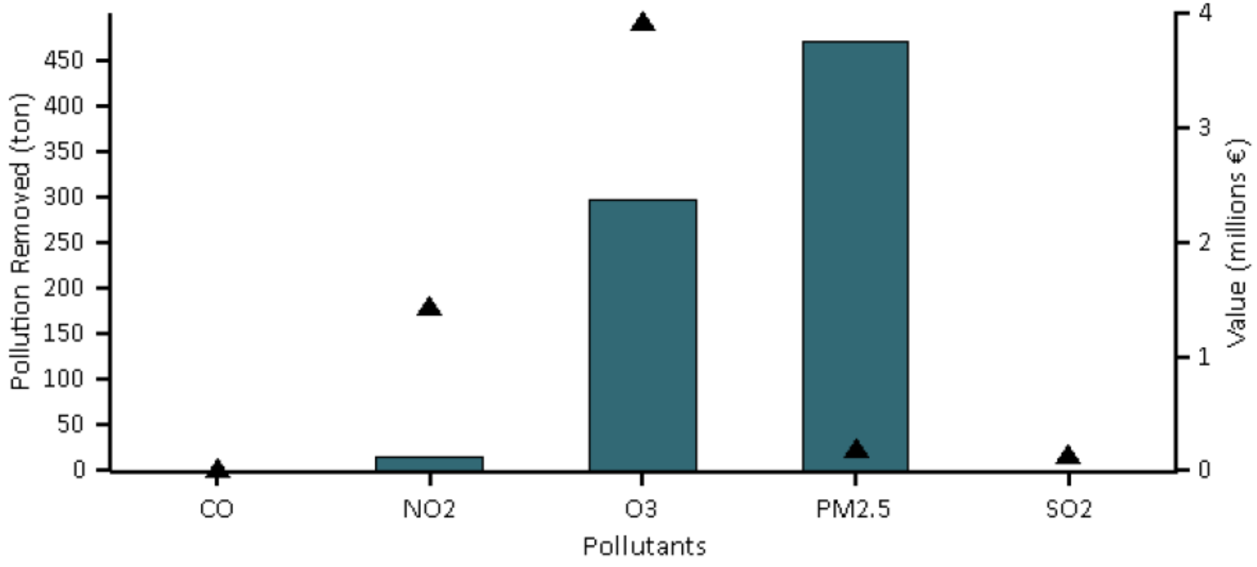
Type of Ecosystem services	Name of ecosystem services (Benefits)	Measurement unit	Agricultural areas		Artificial surfaces		Forest and seminatural areas	
			Mean	Standard error of mean	Mean	Standard error of mean	Mean	Standard error of mean
Provisioning	Leaf biomass	kg/ha	414.36	155.33	969.18	257.26	5972.28	418.60
	Edible values	score	2.78	1.24	2.67	0.71	30.47	3.35
	Medicinal values	score	2.85	1.26	3.33	0.93	35.92	3.50
	Ornamental values	score	1.41	0.62	2.31	0.74	13.27	1.84
	Others	score	0.80	0.30	1.85	0.55	16.48	2.18
	Carbon Storage	kg/yr	276.11	101.00	505.87	116.86	3602.21	350.89
Regulating	Gross Carbon Sequestration	kg/yr	18.07	5.76	28.63	5.21	172.03	7.86
	Potential Evapotranspiration	m^3/yr	6.95	2.53	18.23	5.61	103.01	6.89
	Evaporation	m^3/yr	1.55	0.56	4.06	1.25	22.88	1.53
	Transpiration	m^3/yr	1.31	0.48	3.44	1.06	19.37	1.30
	Water Intercepted	m^3/yr	1.56	0.57	4.07	1.25	22.95	1.54
	Avoided Runoff	m^3/yr	0.26	0.10	0.71	0.23	3.94	0.28
	Oxygen Production	kg/yr	48.18	15.37	76.37	13.89	458.85	20.95
	Isoprene	g/yr	31.87	17.76	24.67	12.09	326.83	62.70
	Monoterpene	g/yr	28.32	21.27	102.72	34.68	625.52	81.24
	O3	g/yr	114.18	41.49	299.15	91.93	1690.50	113.16
	NO2	g/yr	42.08	15.29	110.24	33.88	622.96	41.70
	SO2	g/yr	3.51	1.28	9.20	2.83	52.04	3.48
	PM2.5	g/yr	6.46	2.35	16.95	5.21	95.71	6.41
Supporting	Tree microhabitat abundance	count	24.69	9.16	37.31	10.51	125.33	14.31
	Tree microhabitat richness	count	3.02	1.07	3.26	0.80	19.38	1.87
	Tree species diversity	Shannon index	0.17	0.06	0.46	0.07	1.24	0.06
	Tree structure diversity	Gini coefficient	0.58	0.07	0.52	0.04	0.70	0.02

Example – regulating ecosystem services

Air quality improvement

Removal of 740 metric ton per year of pollutants such as PM2.5, O3, CO and SO2

Economic values: 7,2 Mio. Euro/Jahr

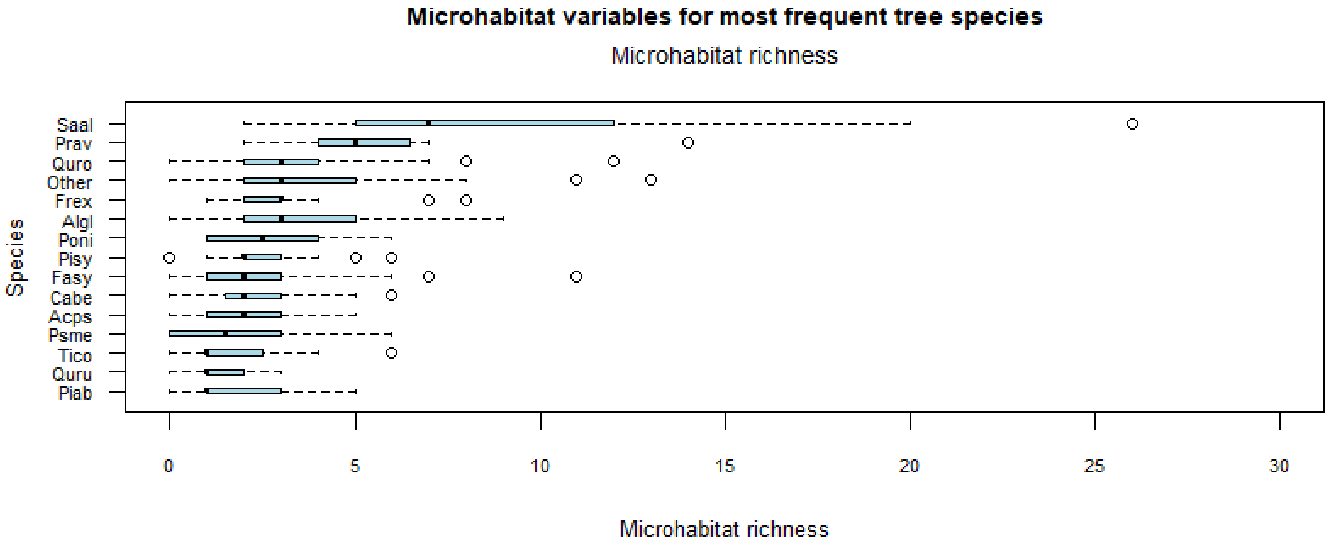


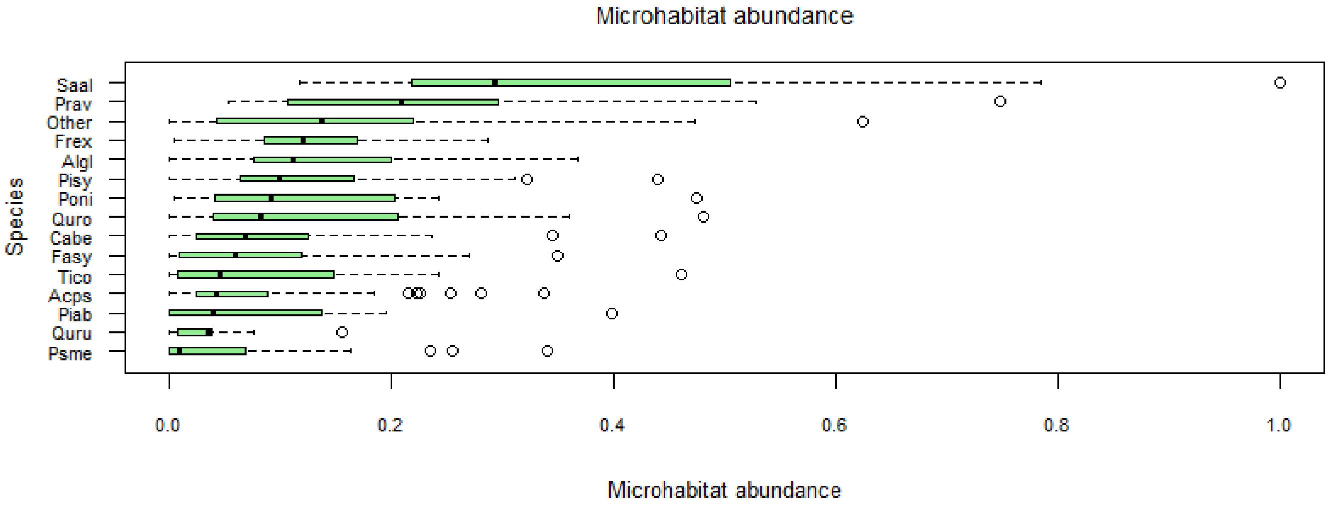
▲ Pollution removal

Bars: monetary values

Modelled from Software i-Tree Eco

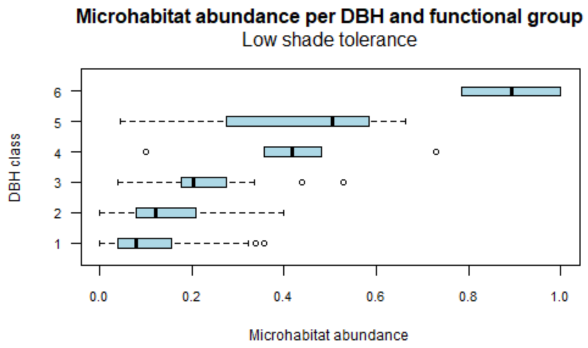
Microhabitat richness and abundance

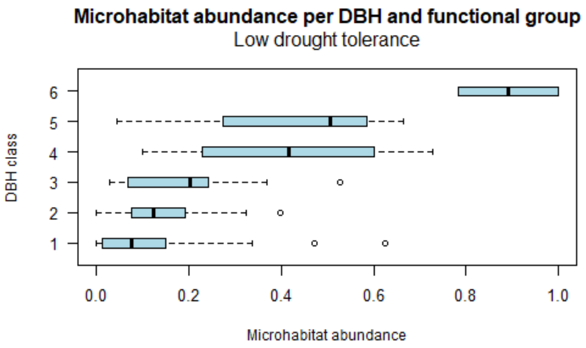


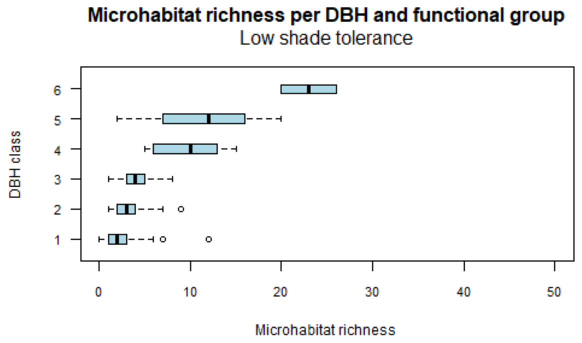


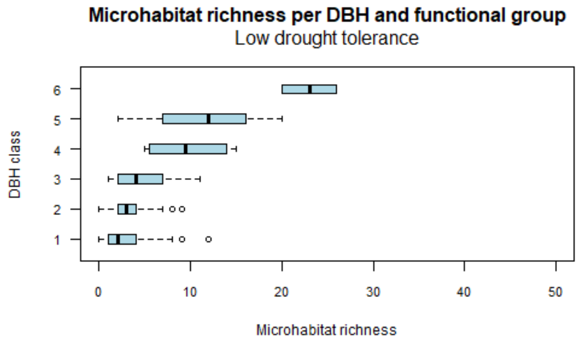
High inter specific variation in microhabitat Richness and abundance

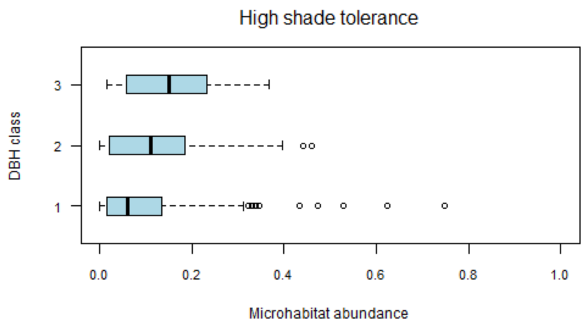
Microhabitat richness and abundance

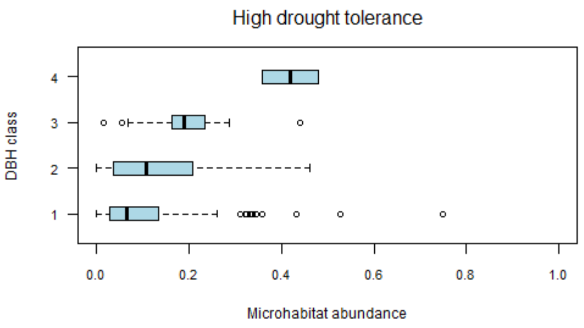


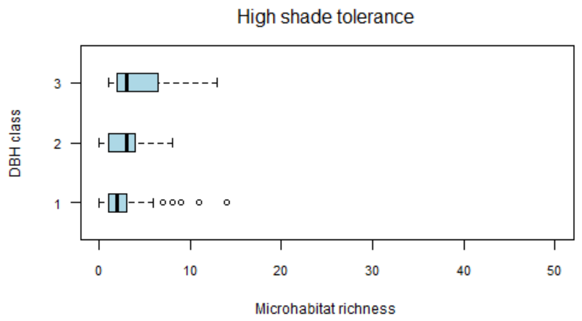


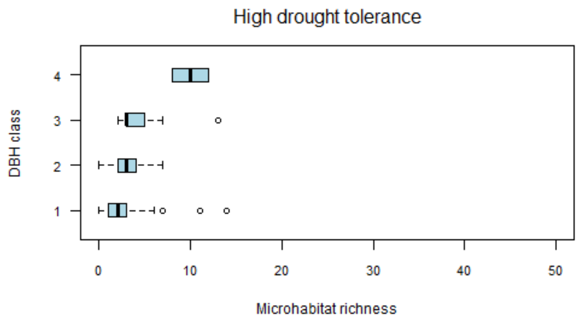






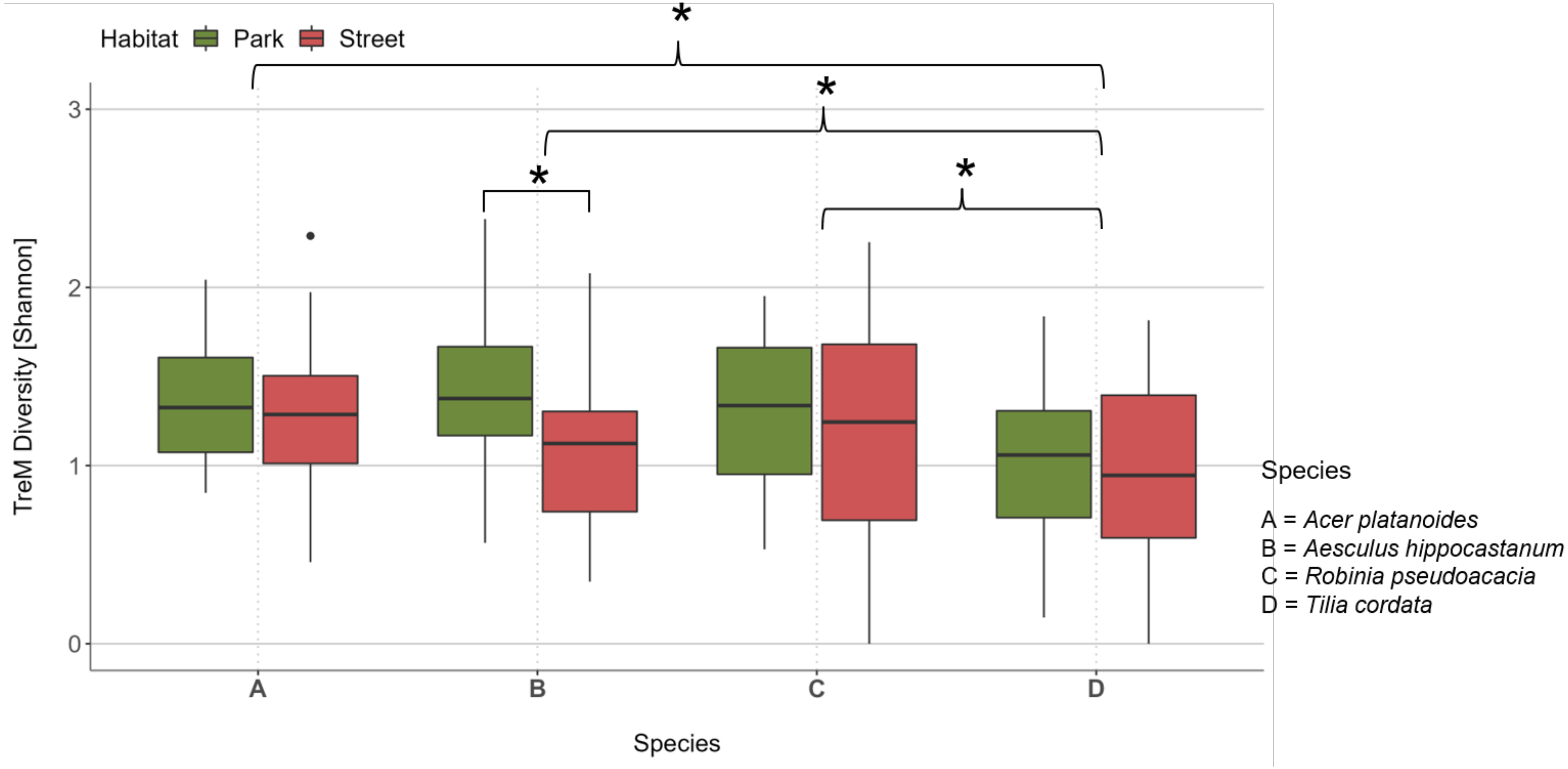






Big trees mean more microhabitat richness and abundance

Microhabitat richness and abundance



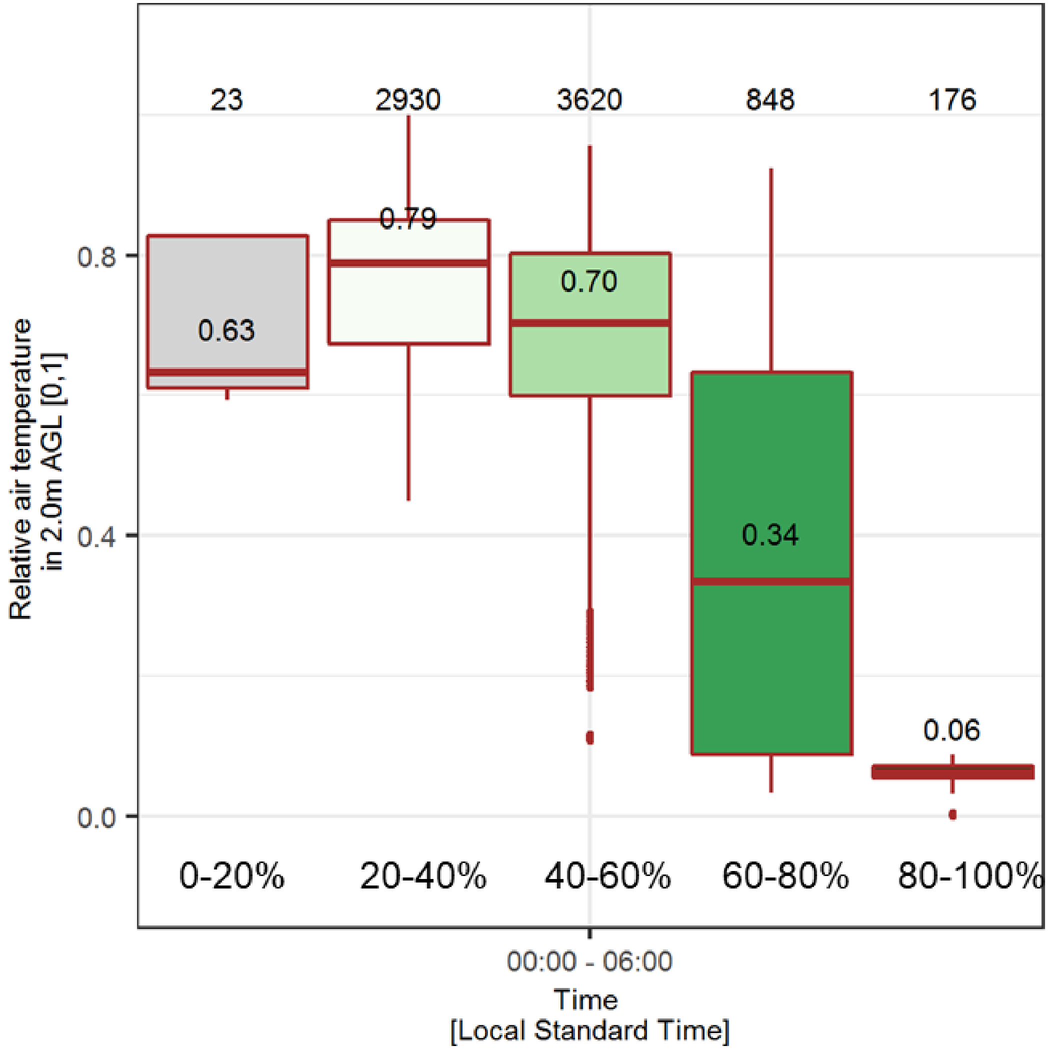
Park trees had more microhabitat richness than street trees

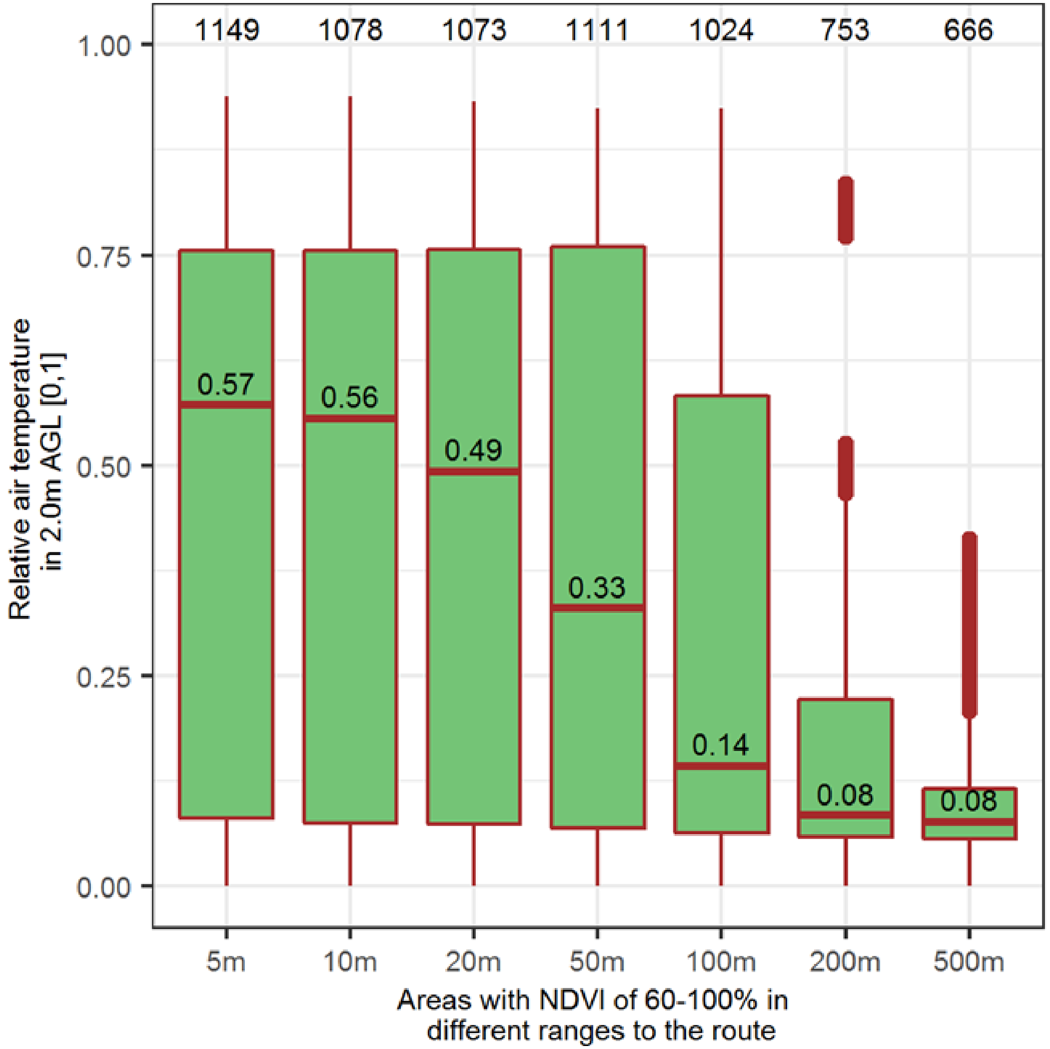
Bat activties and health of native and exotic trees

- Native oaks (*Quercus robur*) support more bat diversity in Karlsruhe than exotic red oak (*Quercus rubra*)

- Exotic red oaks (*Quercus rubra*) were healthier than native oaks

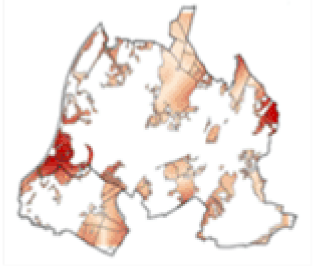
Spatial neighborhood analysis – NDVI and relative air temperature (0.00 to 06.00 UTC)





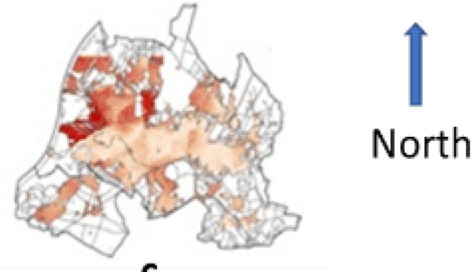
High trade-offs between supporting and regulating ES were found

Forest and semi-natural areas



a

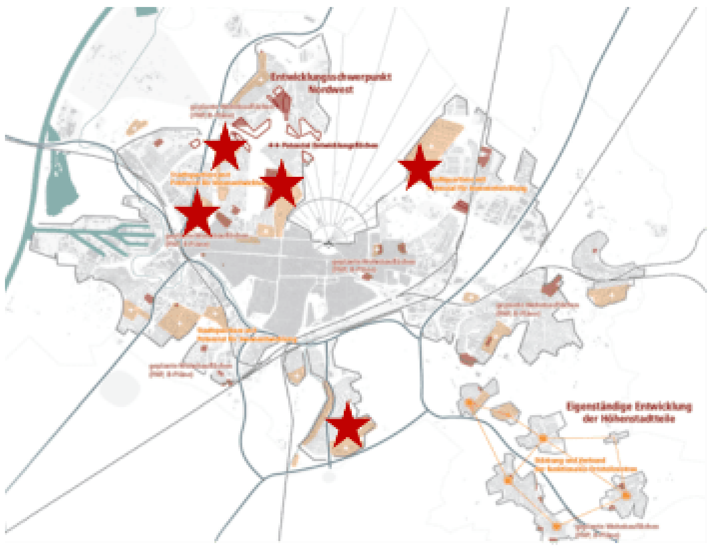
Artificial surfaces



c

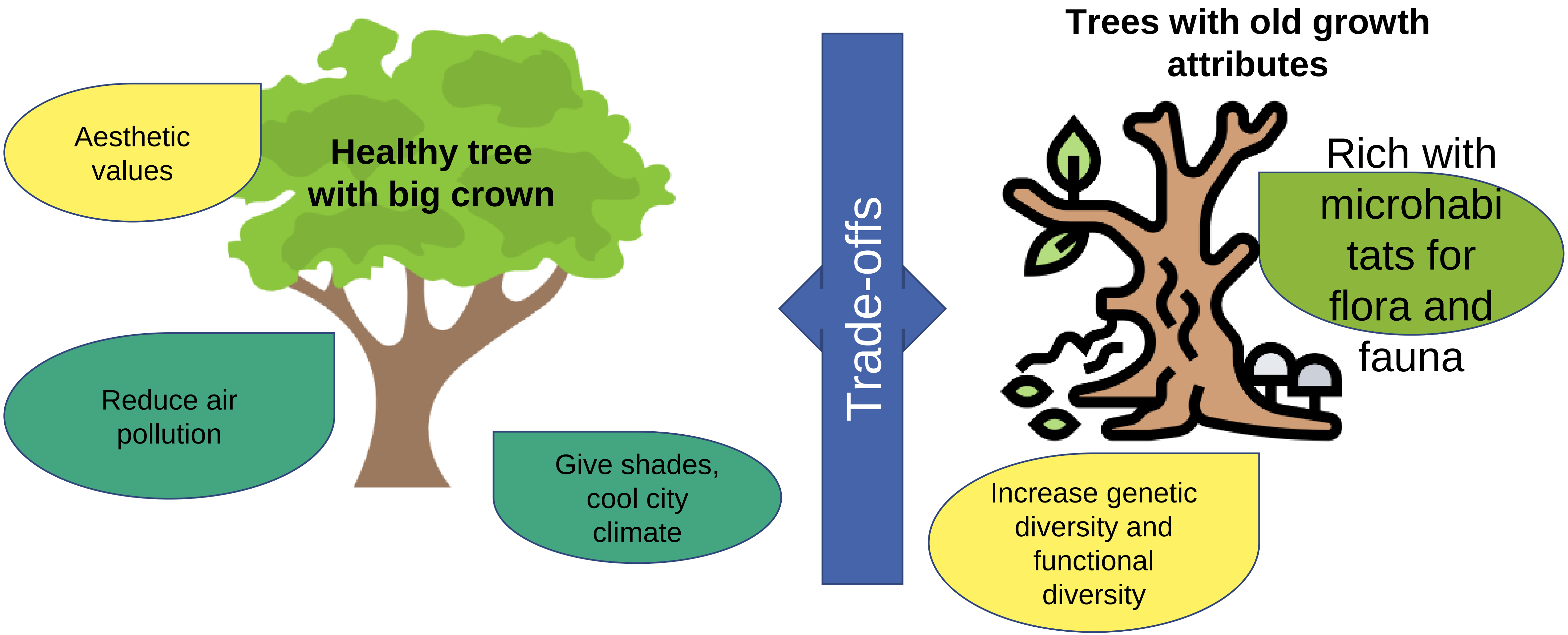
b

d



e

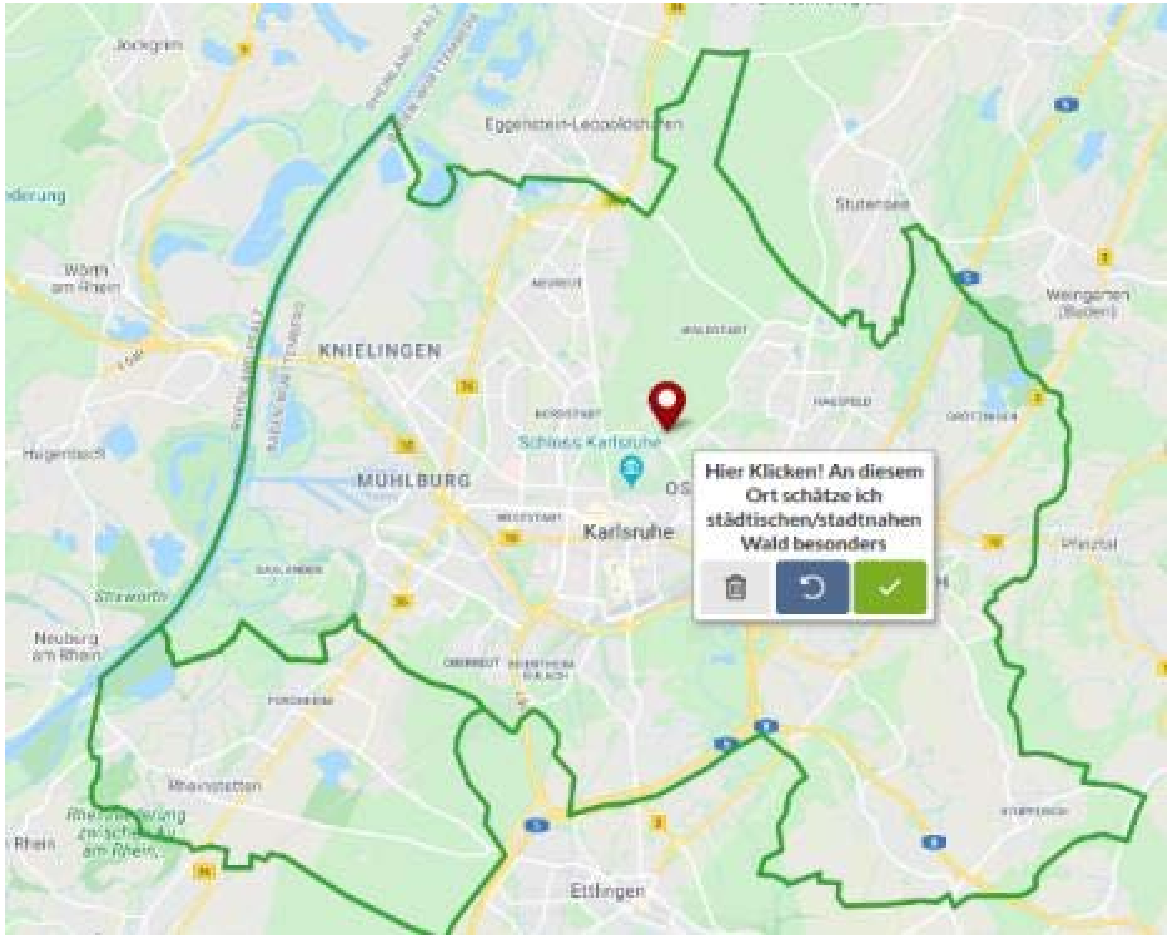
One of the reasons for trade-off



Cultural ecosystem services (CES)

(1) How do the residents of Karlsruhe and Rheinstetten evaluate the cultural ecosystem services of urban forests?

(2) What impact has the COVID-19 pandemic had on these perceptions and the value citizens attribute to the urban forest?



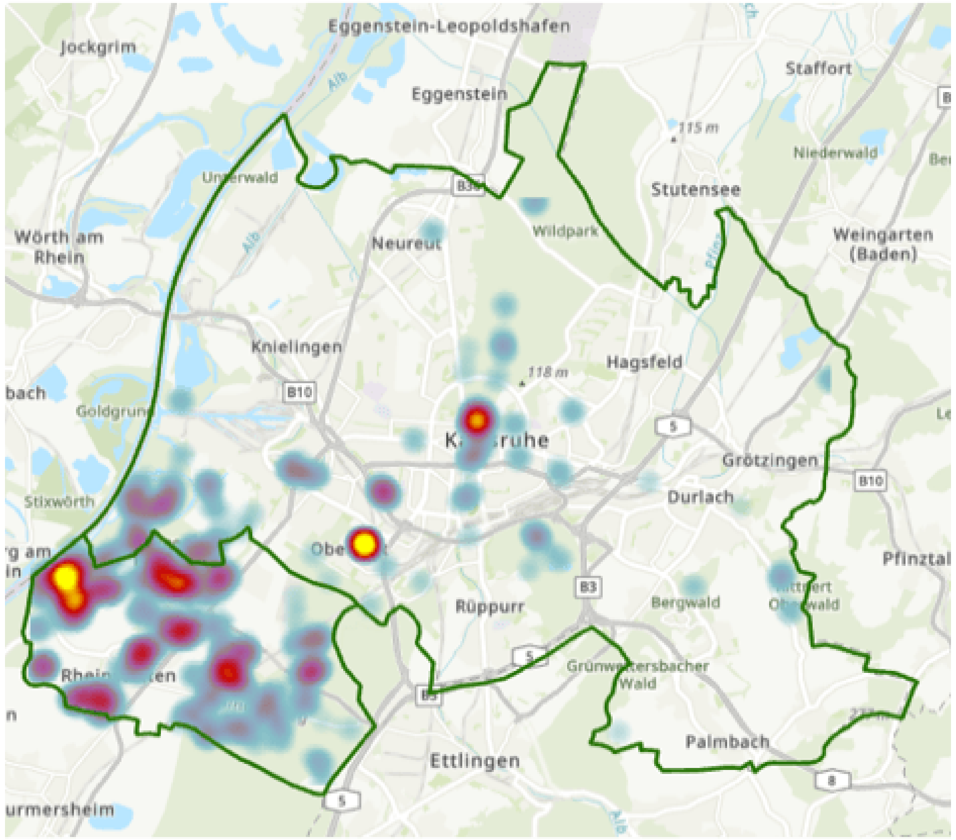
The survey was conducted in August and September 2020.

A total of 501 citizens from Karlsruhe and Rheinstetten took part in the survey.

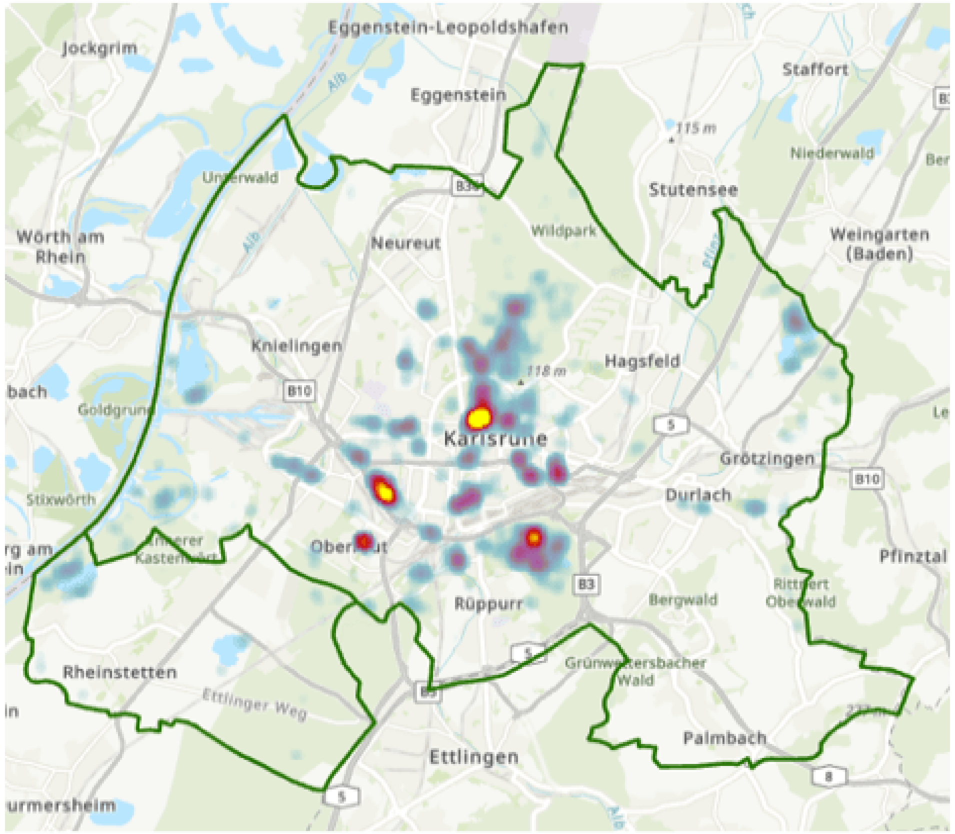
Comparison of CES evaluation

Karlsruhe Institute of Technology

Residents of Rheinstetten
(n=97; 316 evaluated points)



Residents of Karlsruhe
(n=402; 1253 evaluated)



low

high

Density of selected sites (weighted by the sum of the perception of all values of CES)

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Influence of Covid-19 pandemic

> 90%

… of respondents indicated that the urban and peri-urban forest was particularly important to his/her well-being during the COVID-19 pandemic.

70%

… of respondents visit the urban and peri-urban forest more often during the COVID-19 pandemic tha before.

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High public appreciation for the cultural ecosystem services of urban and peri-urban forests during the COVID-19 pandemic

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Conflicts between recreation services and climate change adaptation

Visitors want to go more to urban forests in during and after covid

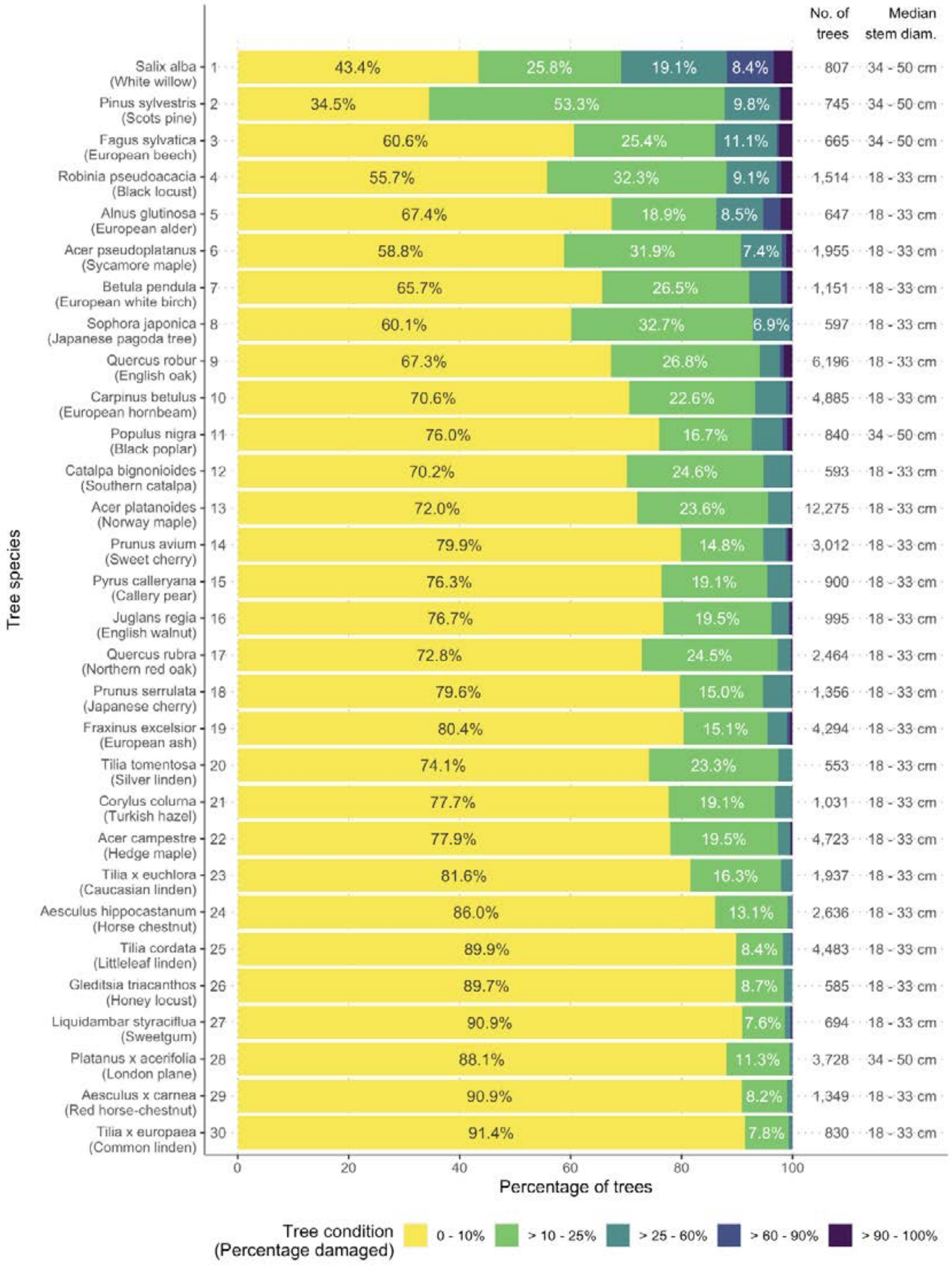
But many urban forests needs some time to recover from continuous drought

Increase in accidents due to falling branches

Visitor ban is not a solution but needs more awareness development

Crown damage in single standing city trees

- 25 of most common 30 urban tree species have at least 10% or more crown damage



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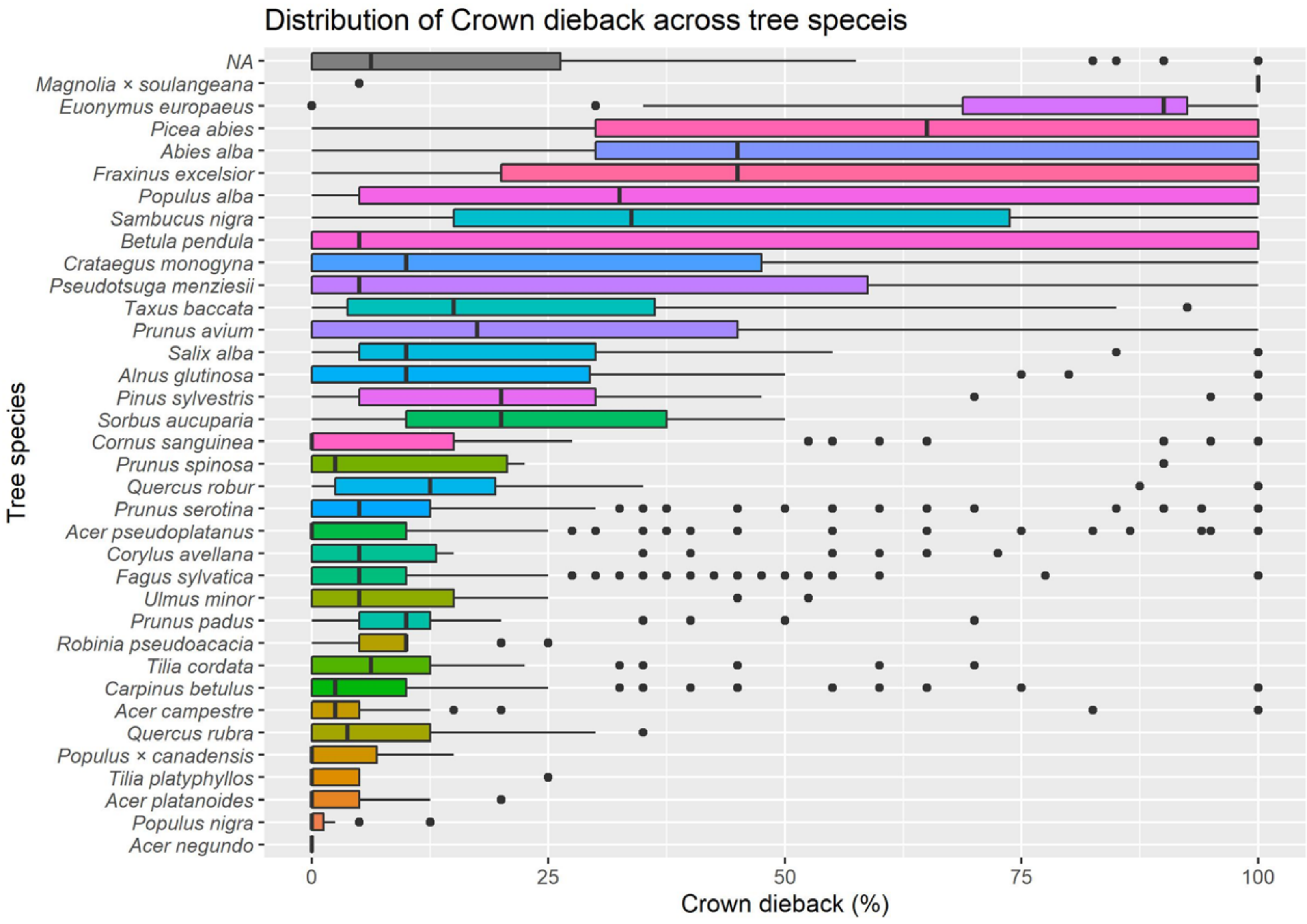
Crown diaback in stand-forming trees inside peri urban forests

- 16 of most common 35 tree species have at least 10% or more crown die-back in peri-urban forests



Growth and Stable Isotope

Correlation between time series (1982-2018)

Tree ring widths (indices)

C and O isotopes

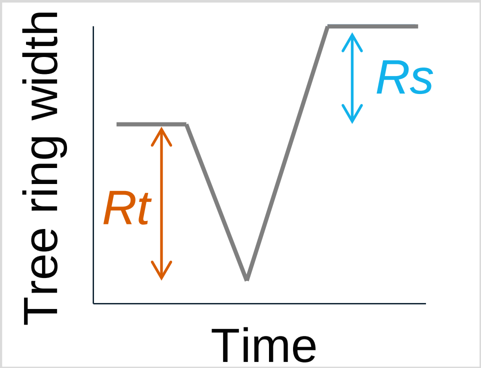
Weather conditions

Growth response to drought (2003, 2011, 2015)

Linear mixed model

Linear model

Resilience indices



Distance to street

Traffic emissions

Soil properties

Tree properties

N isotopes

Radial growth assessment in urban trees:drought and pollution impacts

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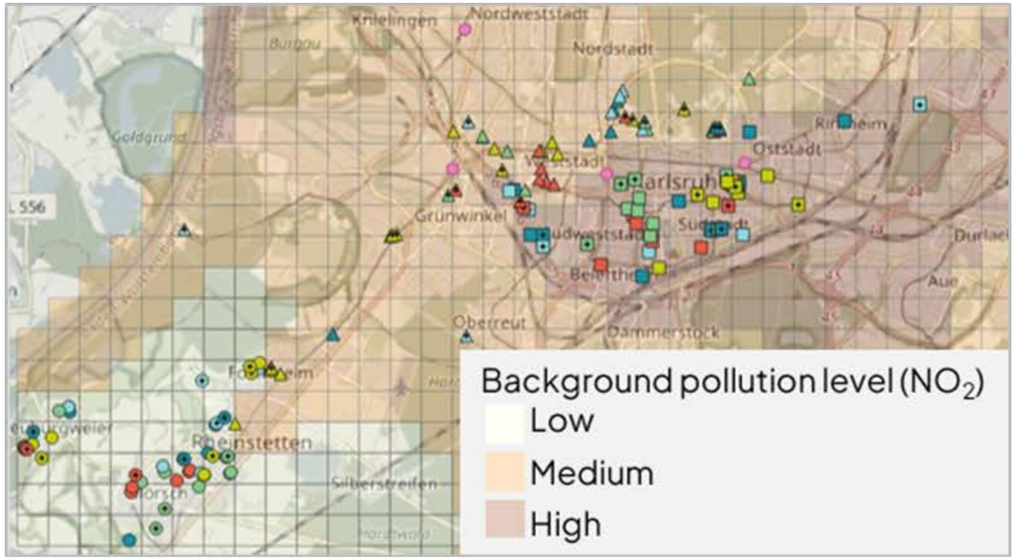
Norway maple
Acer platanoides

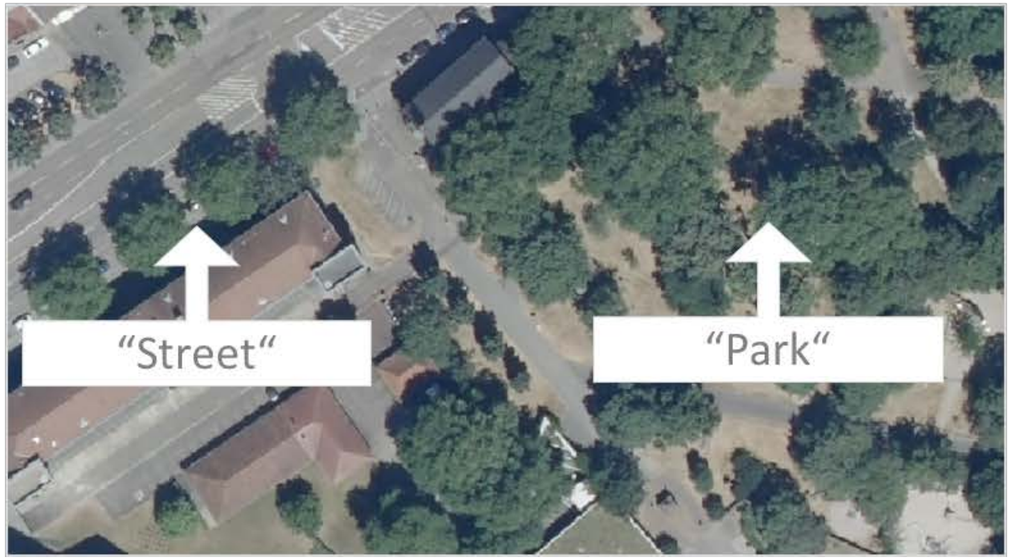
Hornbeam
Carpinus betulus

London plane
Platanus × hispanica

Common oak
Quercus robur

Small-leaved lime
Tilia cordata





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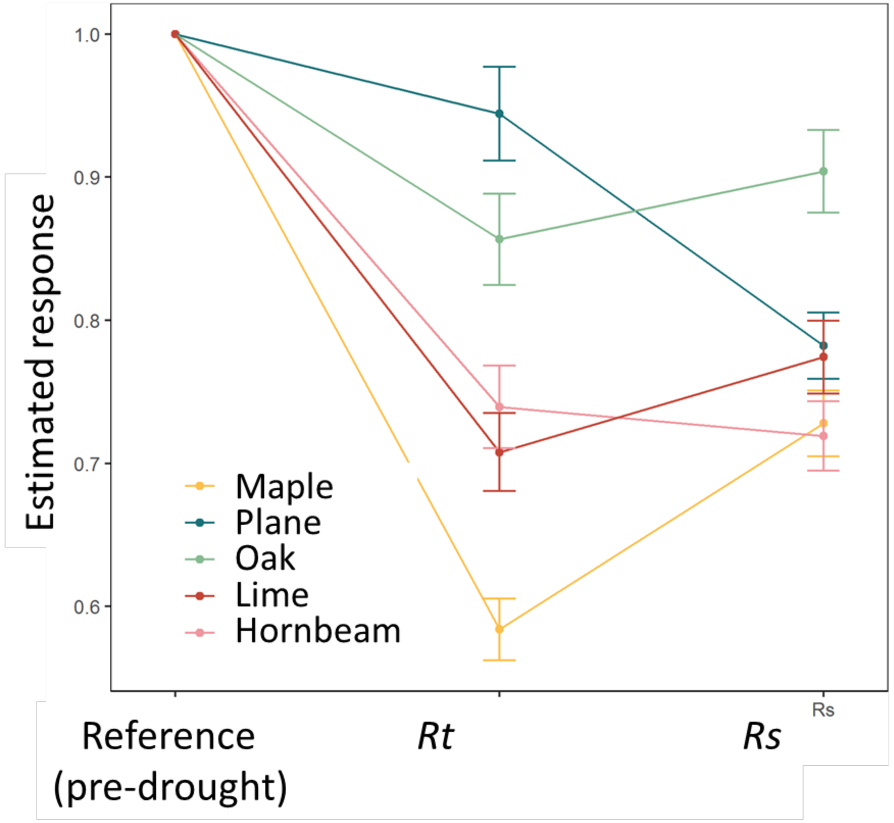
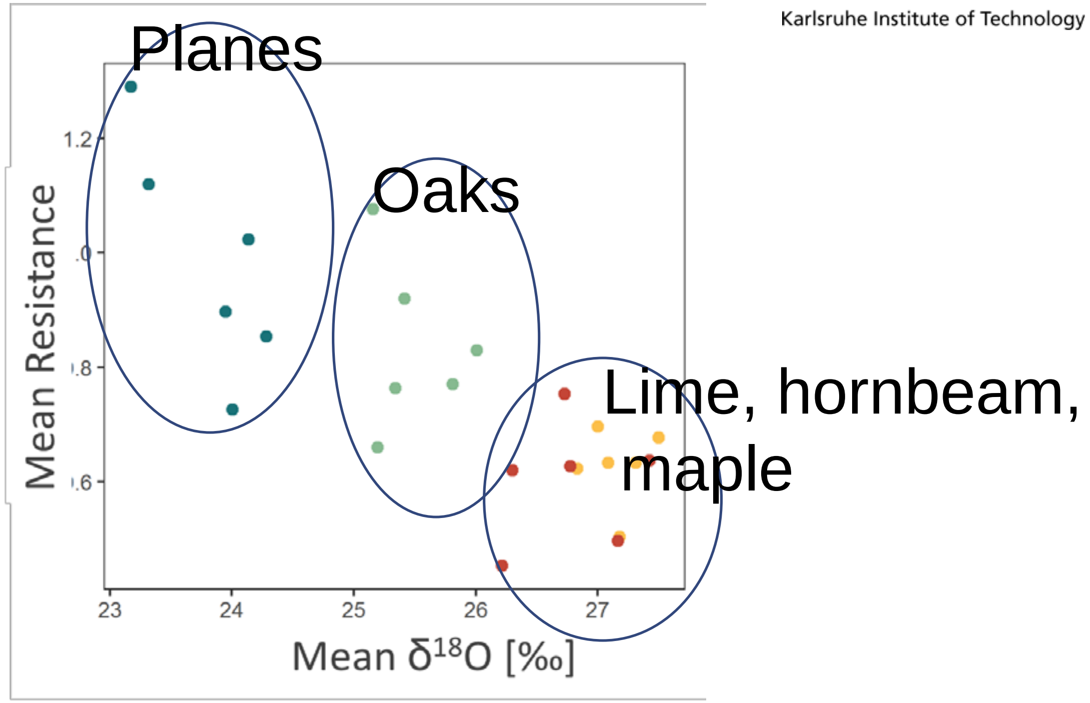
Growth response differs between species



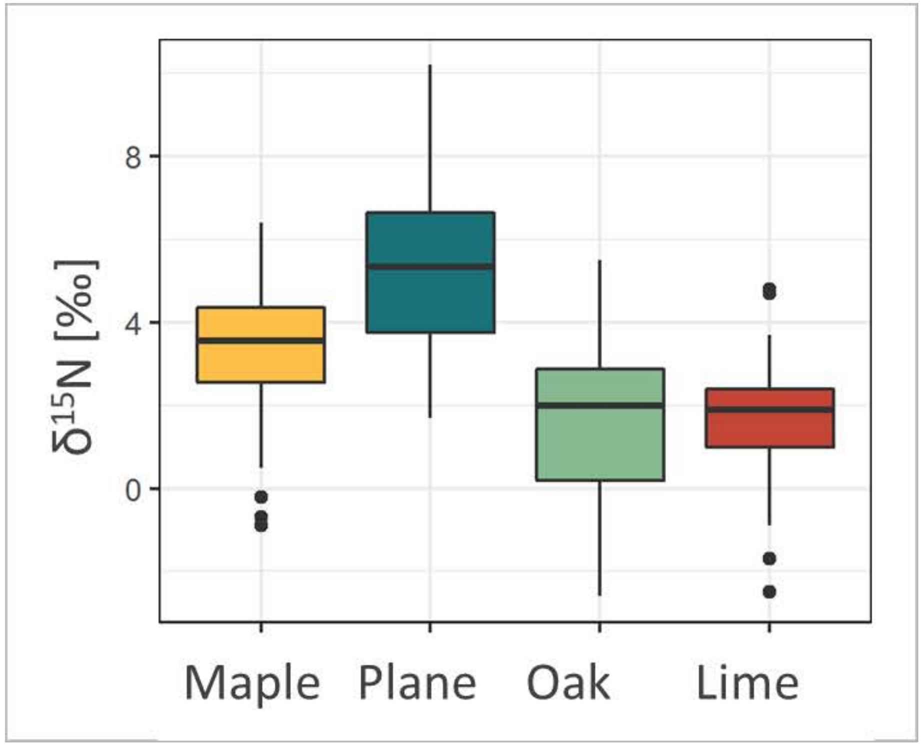


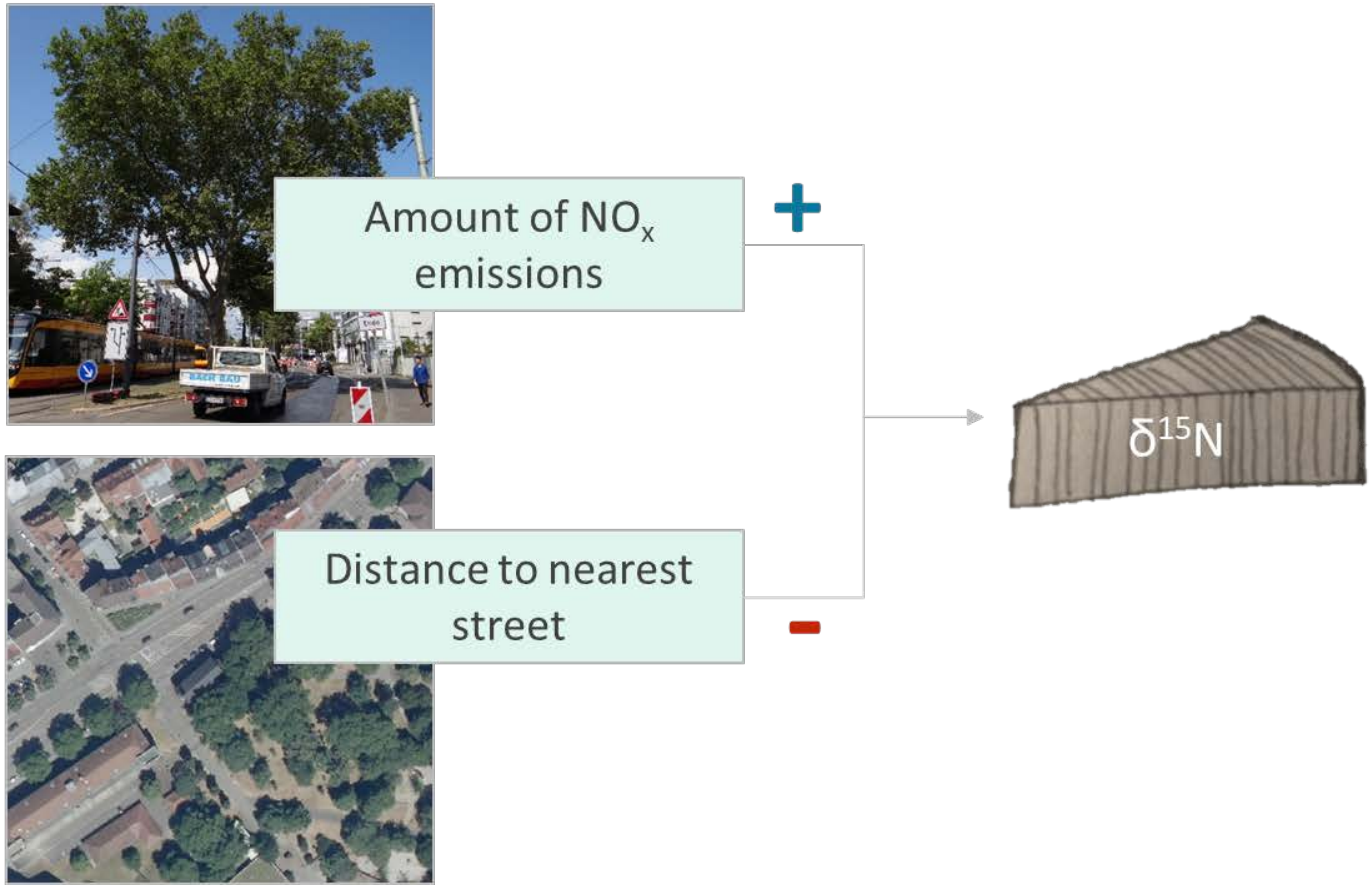
Plane trees have high resistance but low resilience. Native oaks have both high resistance and resilience. Delta O increases with lower resistance.

Precipitation in spring is of high importance for tree growth

Time period: 1982-2018		March	April	May	June	July	Sum JJA (prev. year)
Maple	TRW_i	↑		↑			
	$\delta^{13}C$			↓			
	$\delta^{18}O$			↓			
Oak	TRW_i	↑		↑	↑		
	$\delta^{13}C$						
	$\delta^{18}O$			↓			
Hornbeam	TRW_i			↑			
Lime	TRW_i	↑		↑		↑	
	$\delta^{13}C$			↓			
	$\delta^{18}O$			↓			
Plane	TRW_i						↑
	$\delta^{13}C$						
	$\delta^{18}O$			↓			↑

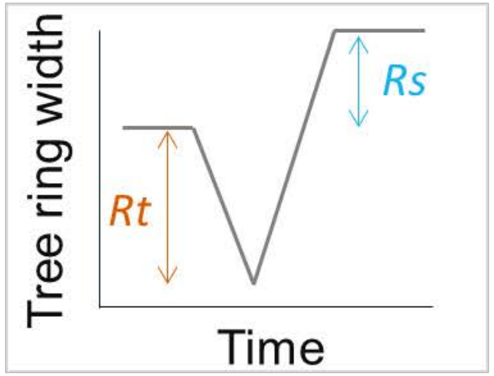
N isotopes concentration varied between species and locations





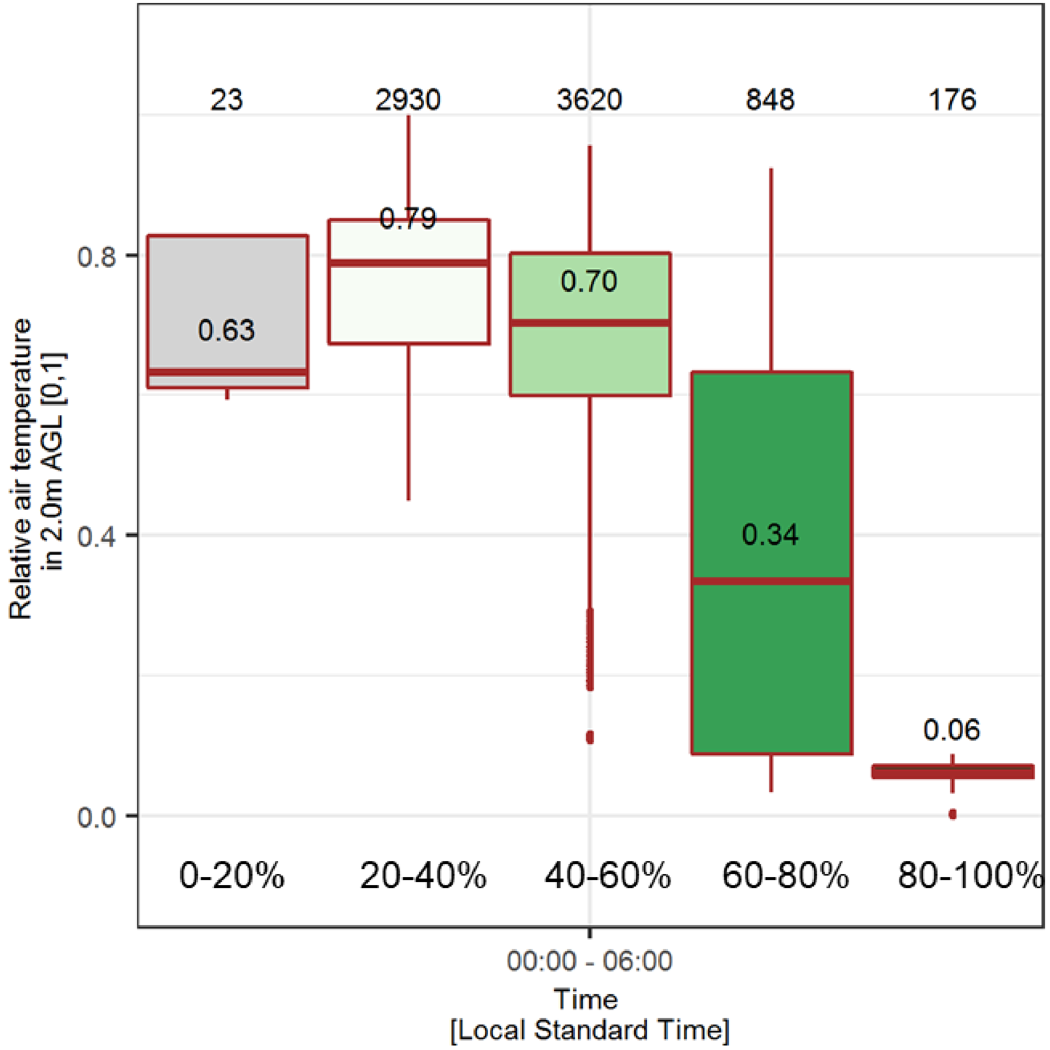
Soil and tree characteristics were main drivers controlling growth, resistance and resilience

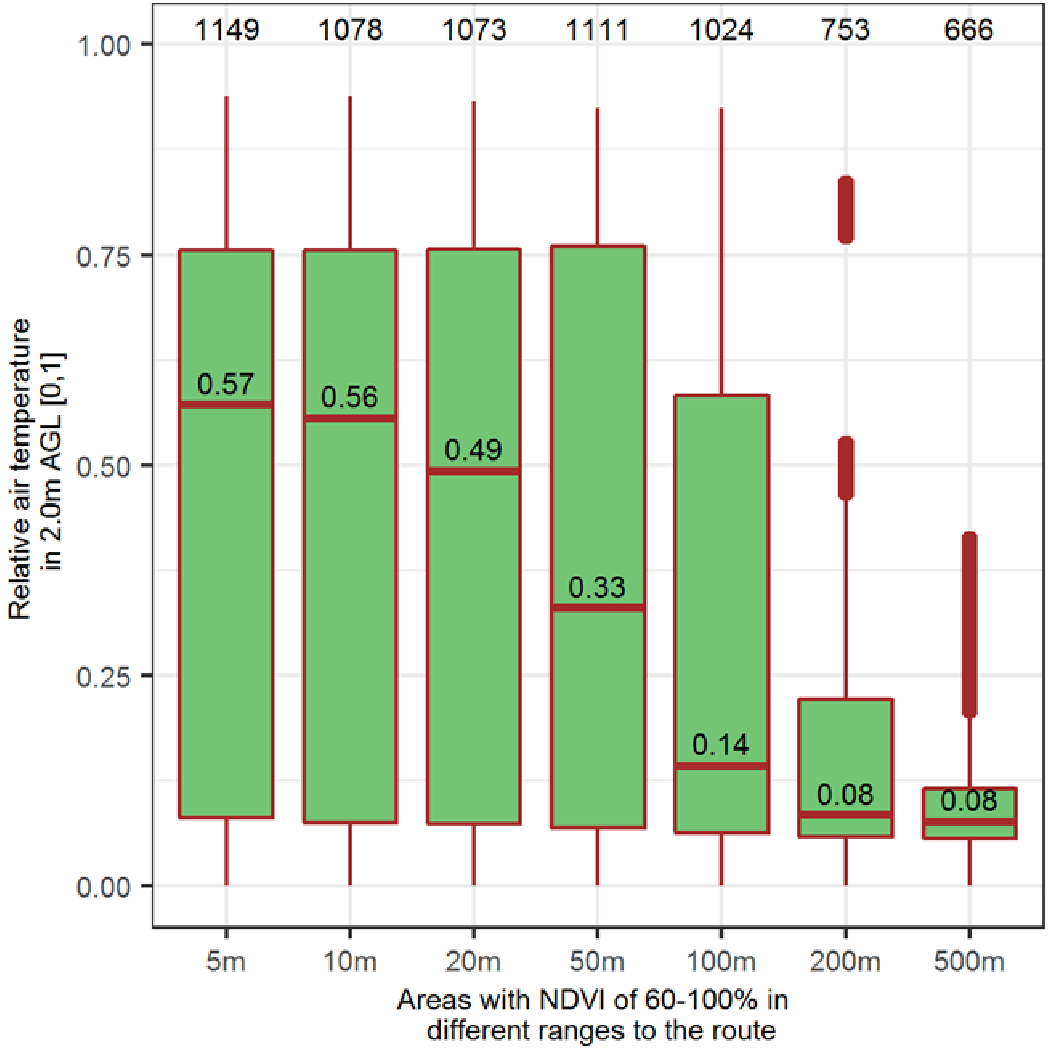
Resilience indices



- ✗ Distance to street
- ✗ Traffic emissions
- (✓) Soil properties
- ✓ Tree properties

Spatial neighborhood analysis – NDVI and relative air temperature (0.00 to 06.00 UTC)





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Creation of transdisciplinary formats in urban forest management

- We created multiple formats of stakeholder engagements involving researchers, city administrations, citizens and other stakeholder
- We used our university's „Real World Lab" (*Reallabor* in German) for this purpose
- We developed guidelines for close to nature urban gardening with citizens and we found high interest among citizens to get engage with researchers and city administrations for improving the management of their private gardens

Main conclusions

- High trade-offs exist between supporting and regulating ecosystem services
- Poor tree health conditions prevailed in the study area
- Spring drought reduced growth
- Drought response varied between species but native European Oaks and exotic Plane trees performed well to drought
- Tree cover and reduce night temperature during heawaves
- High support for the cultural ecosystem services were found

Synthesis

A sustainable supply of ecosystem services and low trade-offs can enhance sustainability. Sustainability may enhance ecological resilience

Involving city as an active project partner helped us to develop transdisciplinary formats. Urban forests are critical infrastructure and improvement of it will increase social resilience of the city

Studying the health of trees based on morphological symptoms during droughts can provide a general picture of resistance and recovery of different tree species in UPFs. A healthy tree population should increase ecological resilience

Perceptions by stakeholders and citizens on the importance of the cultural ecosystem services from urban forests may change over space and time. However, we should continuously monitor these perceptions. This will help us to create an inclusive and just city and increase social resilience

Social-ecological resilience

Forstliche Versuchs- und Forschungsanstalt Baden-Württemberg

The potential of urban forest cover in thermal stress reduction among citizens should be a key component to consider in the creation of future urban forests. This will contribute in social resilience

A retrospective dendroecological and stable isotope study on tree rings of urban species can help us to understand how resilient trees were to past events of drought and improve our understanding of ecological resilience at species level

Deutscher Wetterdienst
Wetter und Klima aus einer Hand

and Systems Analysis

More diversity

Simple, low species park

Complex, high species park

Thank you

Graphic creators: Arturo Romero Carnicero, Caroline Thomas ☺