How to reduce trade-offs between supporting and regulating ecosystem services from urban and peri-urban forests?

Karlsruhe palace, part of the city and palace garden
Photo: Sebastian Mang, KIT

GrüneLunge
www.projekt-gruenelunge.de

Somidh Saha
somidh.saha@kit.edu
www.somidh.com

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Urban and Peri-Urban Forests (UPFs)

UPFs of Singapore (graphic source: New York Times)

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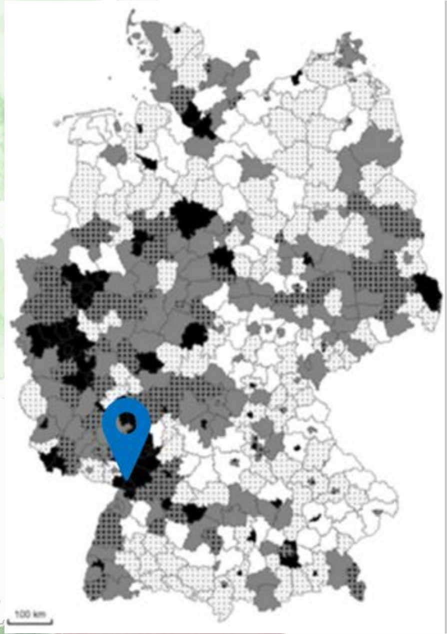
Karlsruhe and global change



Climate change vulnerability

Urbanization

Karlsruhe is vulnerable to the double trouble of climate change impacts and urbanization (DWD 2016, Rannow et al. 2010, Siedentop and Fina 2010)

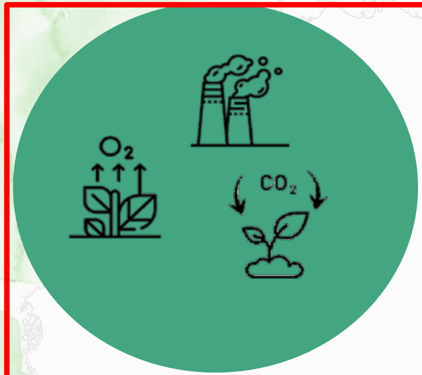
The number of hot days (>25°C) was 50 in 2010s – will increase to 70 by 2040s! (Government of Baden-Württemberg, Stuttgart)

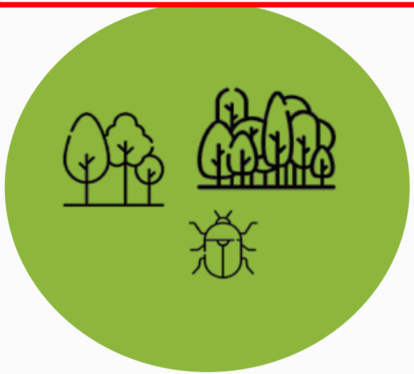
5 challenges of Karlsruhe‘s urban and peri-urban forests

1. ***Crown damage and die-back of trees inside built-up areas of the cities***
2. ***Crown damage and die-back of trees in peri-urban forest stands***
3. ***Densification: the decline of above and below-ground spaces for the trees***
4. ***Biodiversity loss***
5. ***Challenges in tree care and management due to lack of financial resources and human resources***

Some ecosystem services and trade-offs

Ecosystem services





Regulating

- Heat mitigation
- CO2-sequestration und -Speicherung
- Pollution removal
- Air quality improvement
- Erosion control

Supporting

- Flora and fauna diversity
- Habitat diversity
- Genetics and trait

Provisioning

- Timber
- Biomass
- Fruits
- NTFPs

Cultural

- Aesthetic values
- Social cohesion
- Sports
- Mental health

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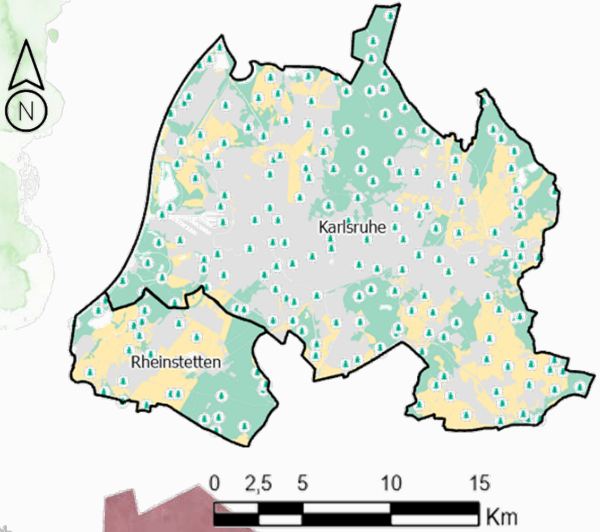
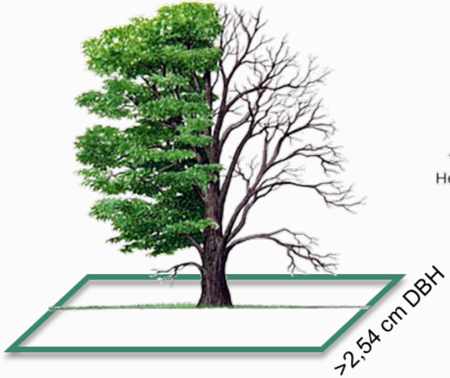
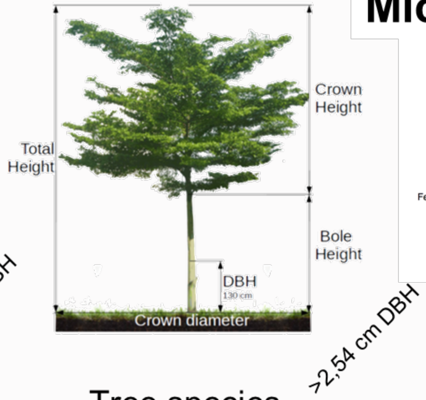
UPFs inventory in Karlsruhe and Rheinstetten

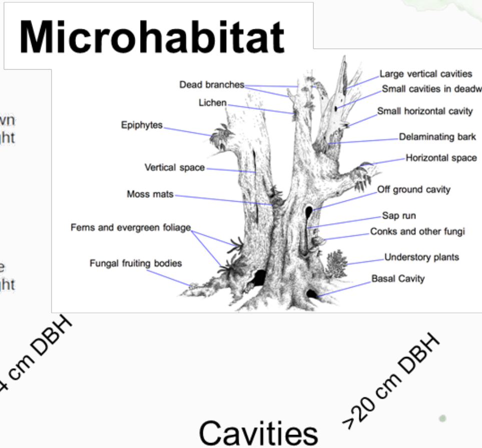




Tree stress symptoms
Crown dieback
Missing crown
Defoliation
Discoloration



Tree species
Tree height
Tree diameter
Crown width



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

201 Plots **2968** Trees **105** Species
(used i-Tree-Eco and i-Tree-Pest detection field guide)

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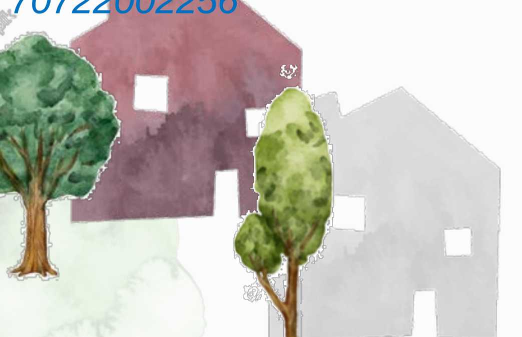
Ecosystem services assessed from 2968 trees (201 plots)

Cueva, J.,…, **Saha**, S. 2022 *(Sustainable Cities and Society)* *https://www.sciencedirect.com/science/article/abs/pii/S2210670722002256*

Type of Ecosystem services	Name of ecosytem services (Benefits)	Measurement unit	Agricultural areas Mean	Agricultural areas Standard error of mean	Artificial surfaces Mean	Artificial surfaces Standard error of mean	Forest and seminatural areas Mean	Forest and seminatural areas 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	m³/yr	6.95	2.53	18.23	5.61	103.01	6.89
	Evaporation	m³/yr	1.55	0.56	4.06	1.25	22.88	1.53
	Transpiration	m³/yr	1.31	0.48	3.44	1.06	19.37	1.30
	Water Intercepted	m³/yr	1.56	0.57	4.07	1.25	22.95	1.54
	Avoided Runoff	m³/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



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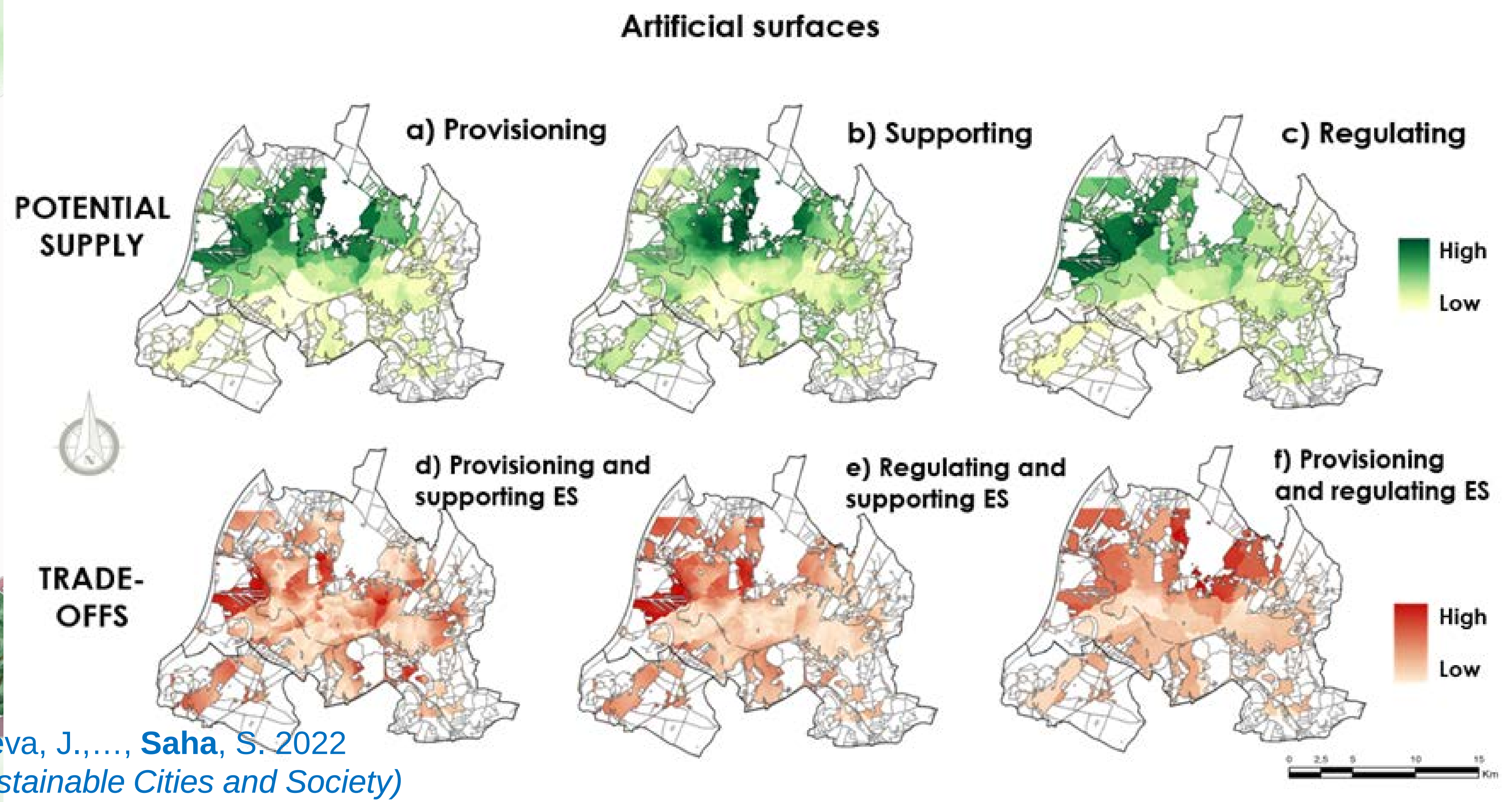
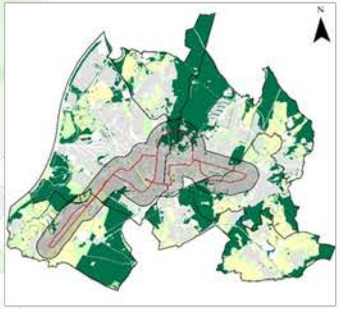
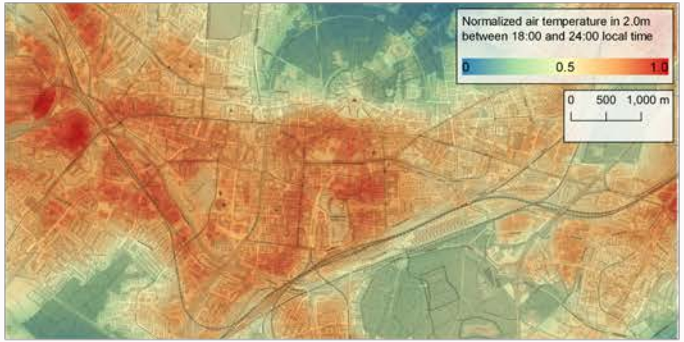
Trade-offs between ES

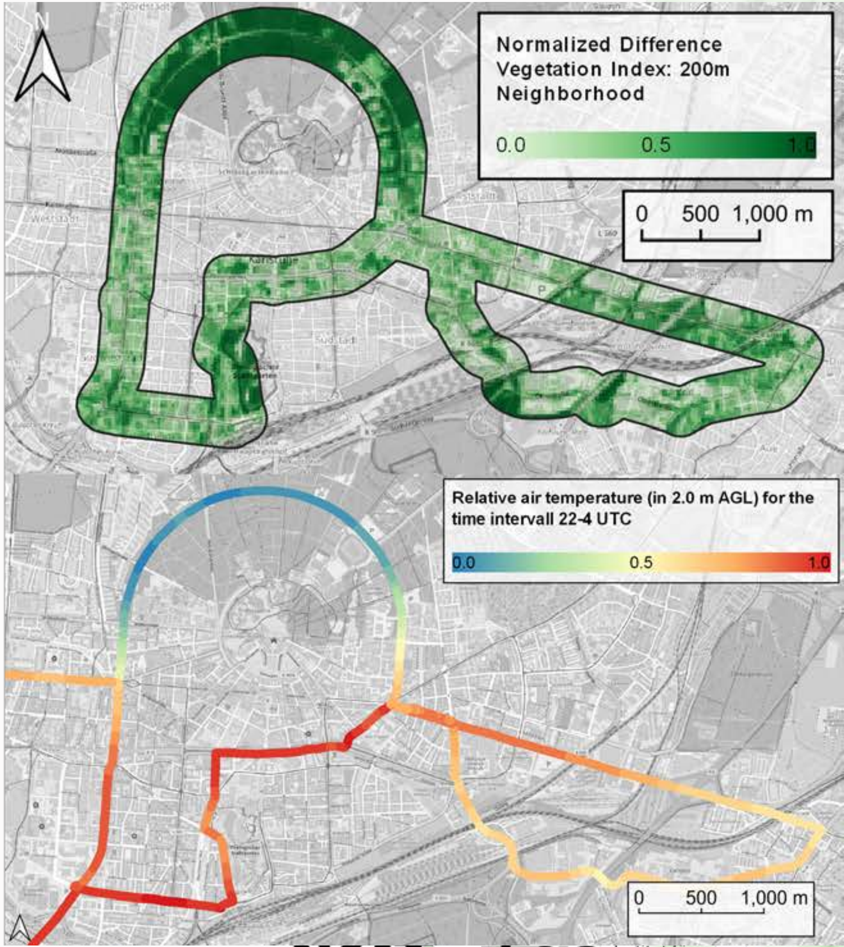


Cueva, J.,…, **Saha**, S. 2022
(Sustainable Cities and Society)
https://www.sciencedirect.com/science/article/abs/pii/S2210670722002256

Microclimatic modeling and linking to tree cover and urban morphology during heatwaves







Graphics and photos:
Marcel Gangwisch/DWD

Gangwisch, M.; ***Saha***, S.; Matzarakis, A. (2023)
(Urban Climate)
https://www.sciencedirect.com/science/article/pii/S2212095523002183

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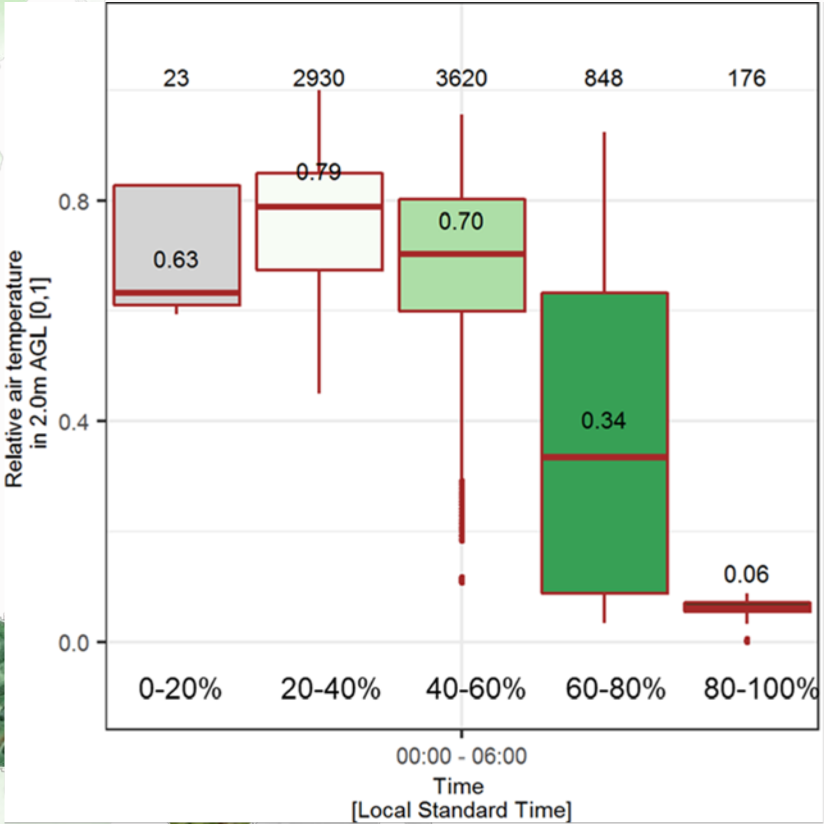
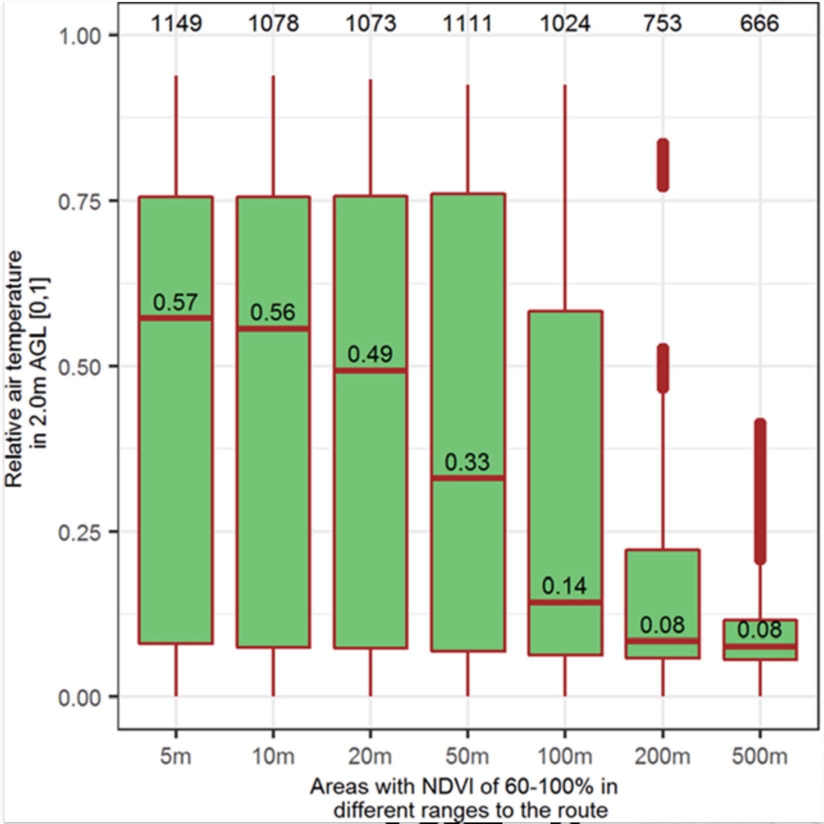
Cooling increased with tree cover percentage and proximity to green space





Gangwisch, M.; **Saha**, S.; Matzarakis, A. (2023)
(Urban Climate)
https://www.sciencedirect.com/science/article/pii/S2212095523002183

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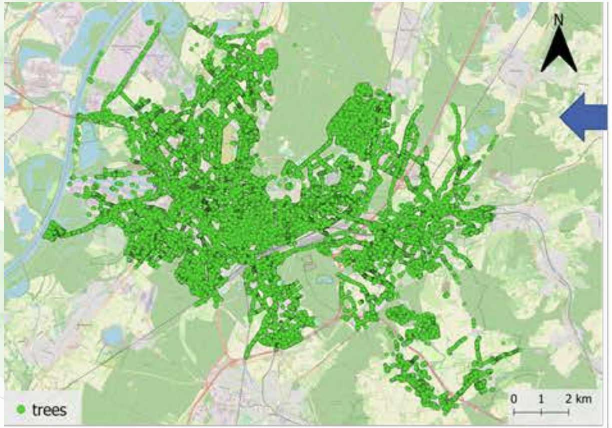
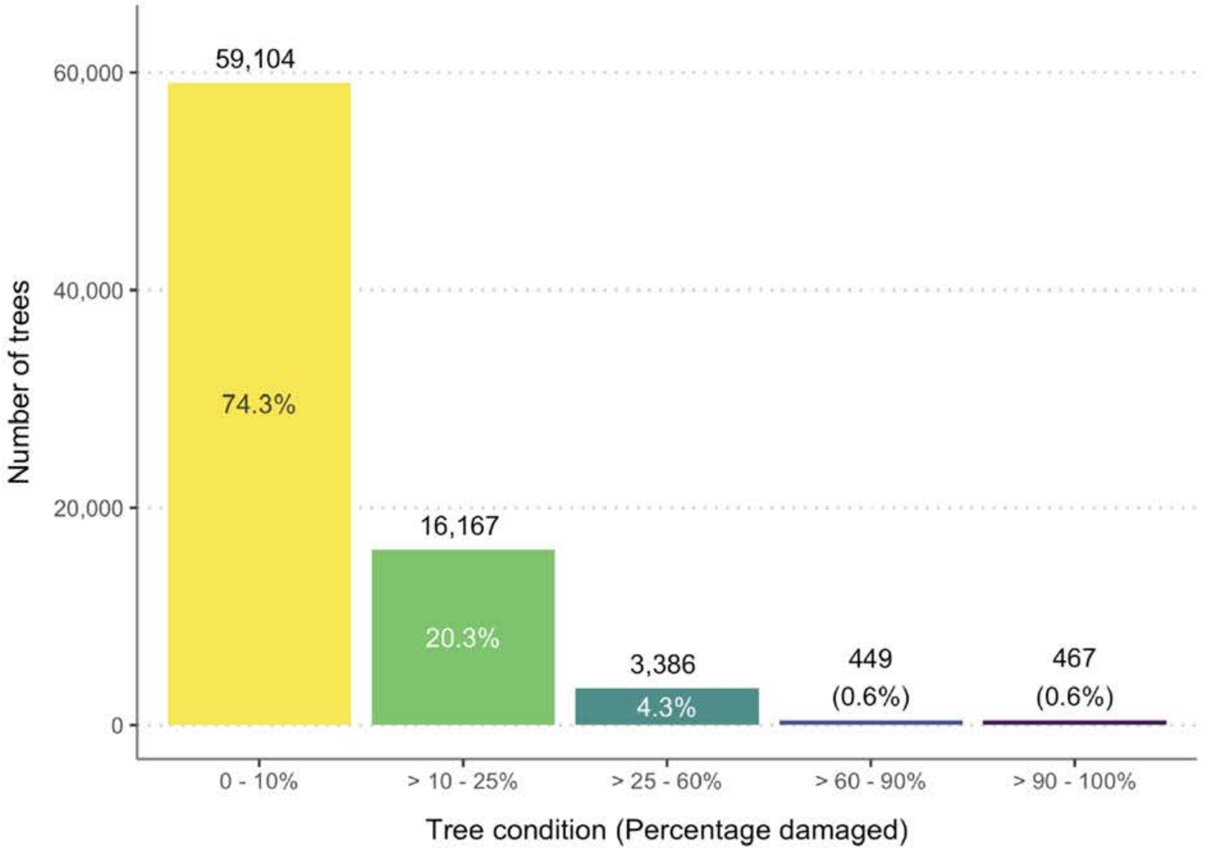
Crown damage of solitary trees

Crown damage in solitary trees

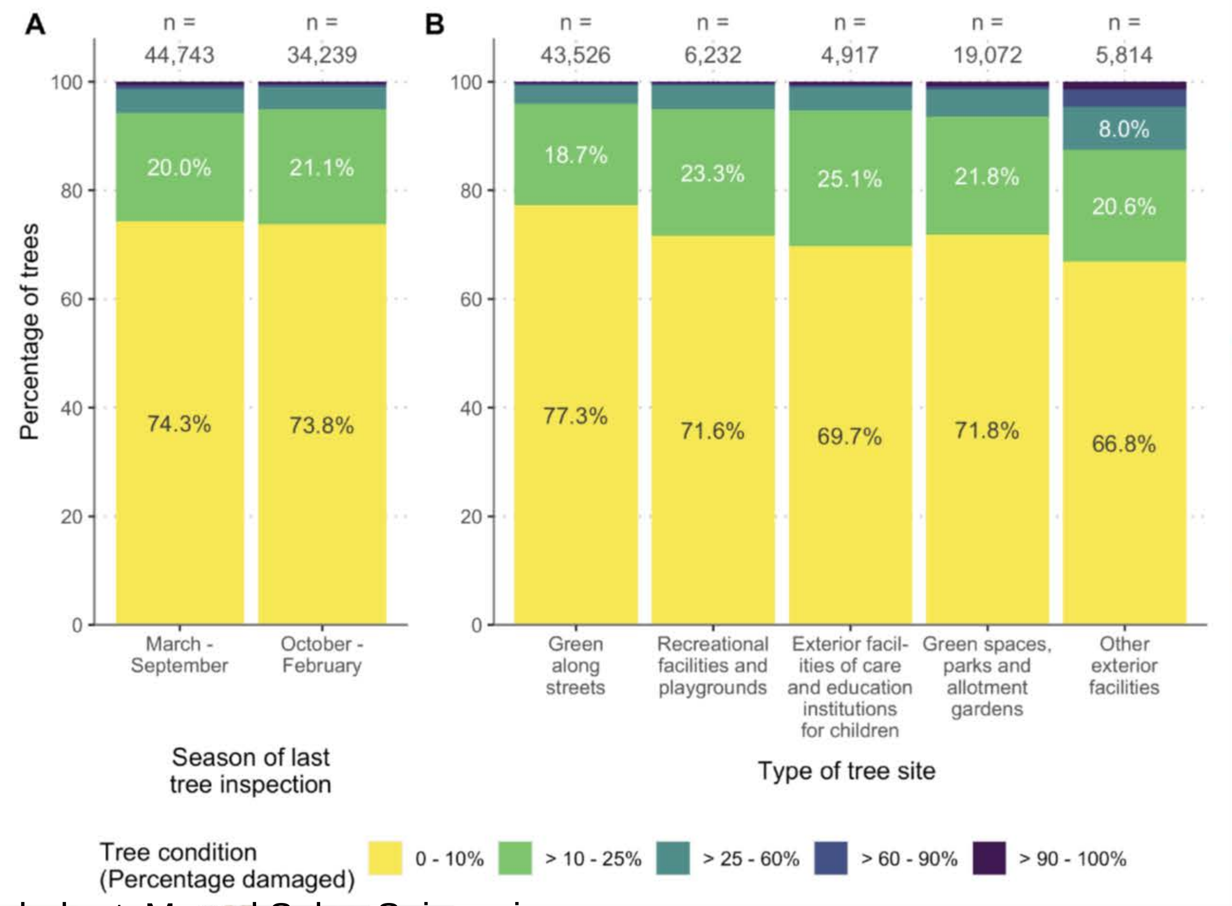


N_{trees} = 79,573



Schobert, M. and Saha, S. (in preparation)

Crown damage in solitary trees



- No difference in terms of the season of tree inspection
- Street trees have the lowest crown damage (pruning effect!)
- Trees in „other exterior facilities“ have the highest crown damage

Schobert, M. and Saha, S. in review

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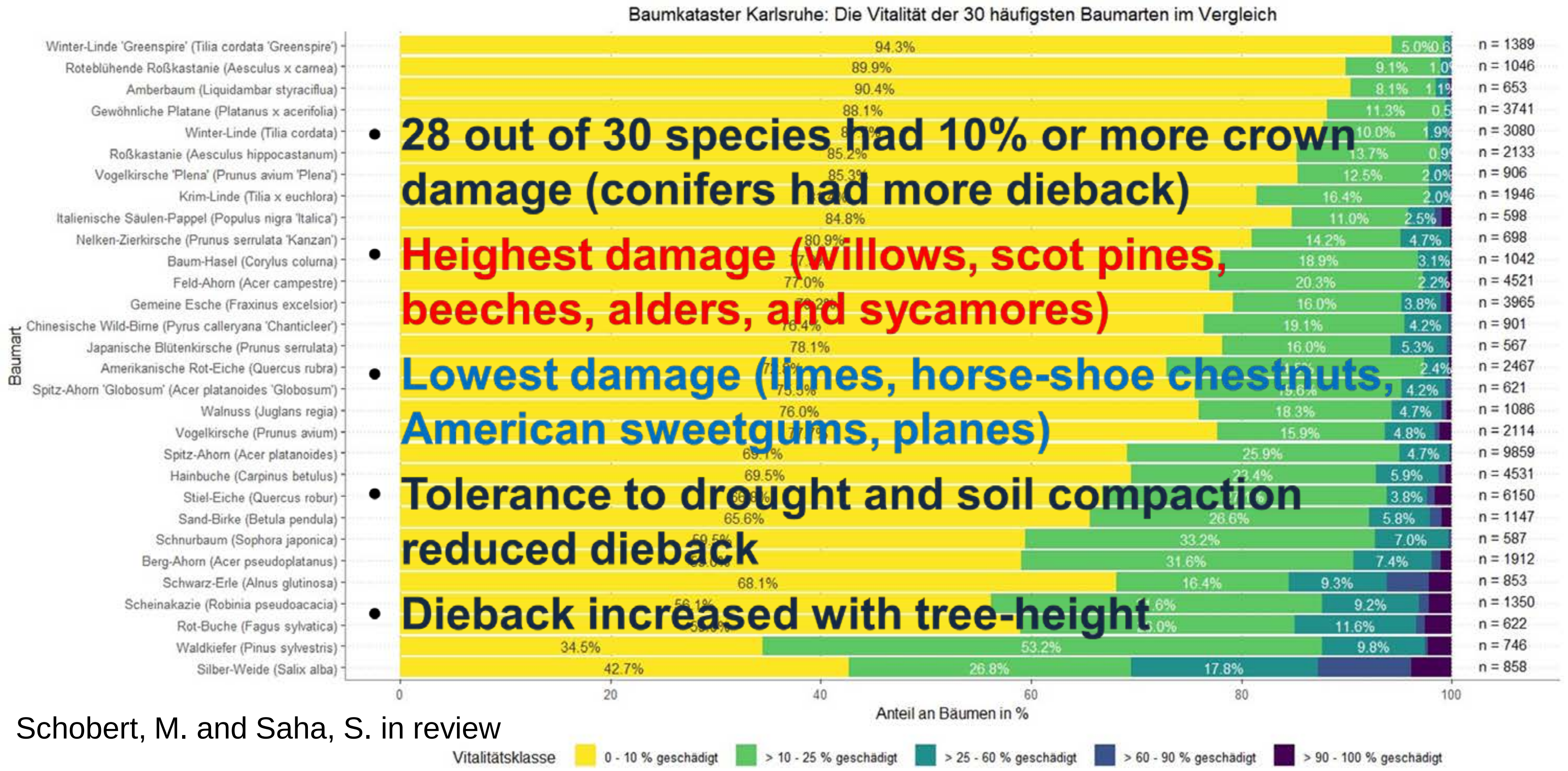
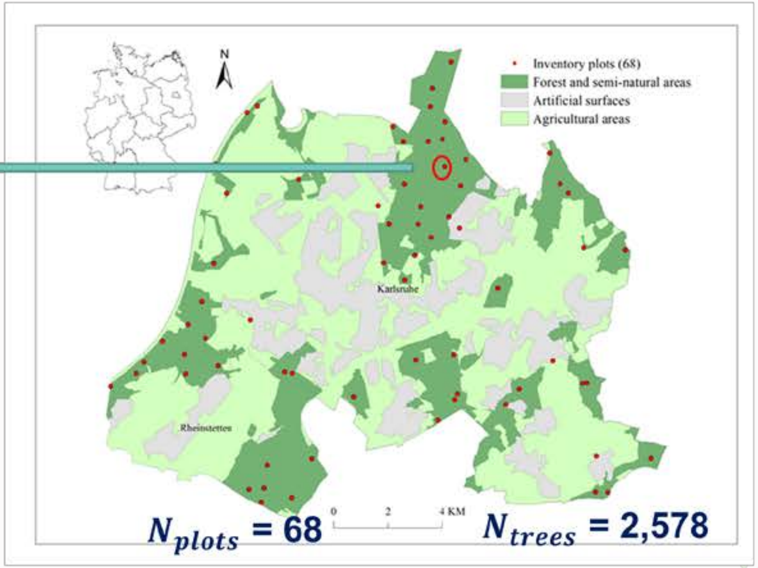
Crown damage in solitary trees

- **28 out of 30 species had 10% or more crown damage (conifers had more dieback)**
- **Heighest damage (willows, scot pines, beeches, alders, and sycamores)**
- **Lowest damage (limes, horse-shoe chestnuts, American sweetgums, planes)**
- **Tolerance to drought and soil compaction reduced dieback**
- **Dieback increased with tree-height**



Schobert, M. and Saha, S. in review

Crown damage in stand-forming trees of peri-urban forests



Photograph and map:
Somidh Saha

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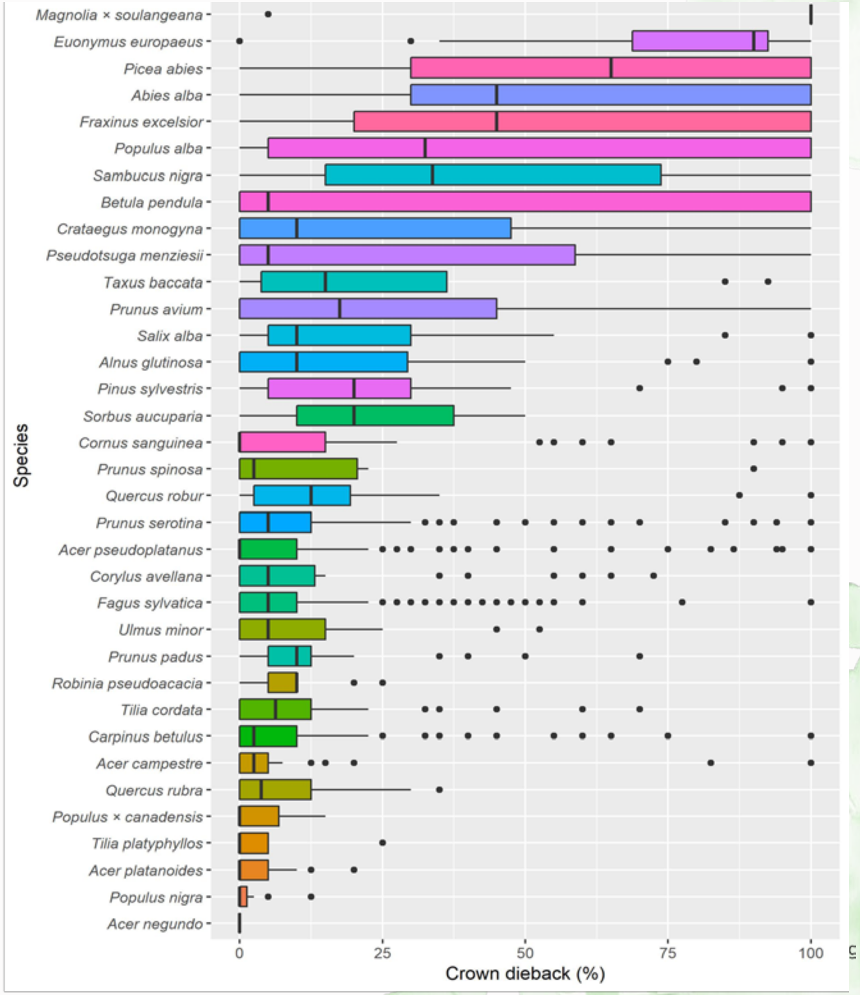
Crown damage in stand-forming trees of peri-urban forests

- 14 out of 28 native species had more than 10% crown die-back
- Xylem cavitation tolerance and drought tolerance reduced dieback
- Competition (stem density) increased dieback
- Highest dieback (spindles, Norway spruces, silver firs, ashes, white poplars)
- Lowest dieback (black poplars, summer limes, Norway maples, red oaks, field maples)



Lyu, H. and Saha, S. (submitted)
Photograph: Somidh Saha

Case study on native and exotic oaks

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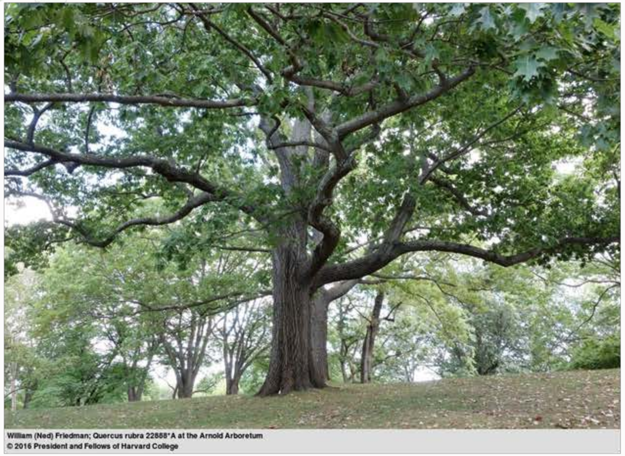
Quercus robur L. (Native Pedunculate Oak or *Stieleiche*)

The Great Allerton Oak of **Calderstones Park, Liverpool** ***(1000 years old)***

- Native species in Germany
- The oldest specimen (known to me!) in Karlsruhe city is 320 years old and located in the main cemetery (*Hauptfriedhof*)
- 6373 pedunculate oak trees in Karlsruhe owned by the Horticulture Department (Gartenbauamt)
- High biodiversity, economic and cultural value

Quercus rubra L. (Exotic North American Red Oak or *Roteiche*)



Habitus
(in Arnold Arboretum, Harvard, USA)

Red oak leaves and acorns

- Introduced to Germany in 18th/19th century
- The **oldest specimen we have studied in Karlsruhe was 150 years old in a park**
- **2538 red oak trees in Karlsruhe** owned by the Horticulture Department (Gartenbauamt)

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Working hypotheses

In Karlsruhe city, exotic *Q.rubra* (red oak) trees have better performance than native Q. robur (pedunculate oak) trees in:

- H1) radial growth;
- H2) tolerance to drought;
- H3) internal trunk defect;
- H4) health symptoms such as crown die-back;
- H5) microhabitat provisions and bat diversity;
- H6), and those responses varied between growing environments (park vs. street) and other factors.

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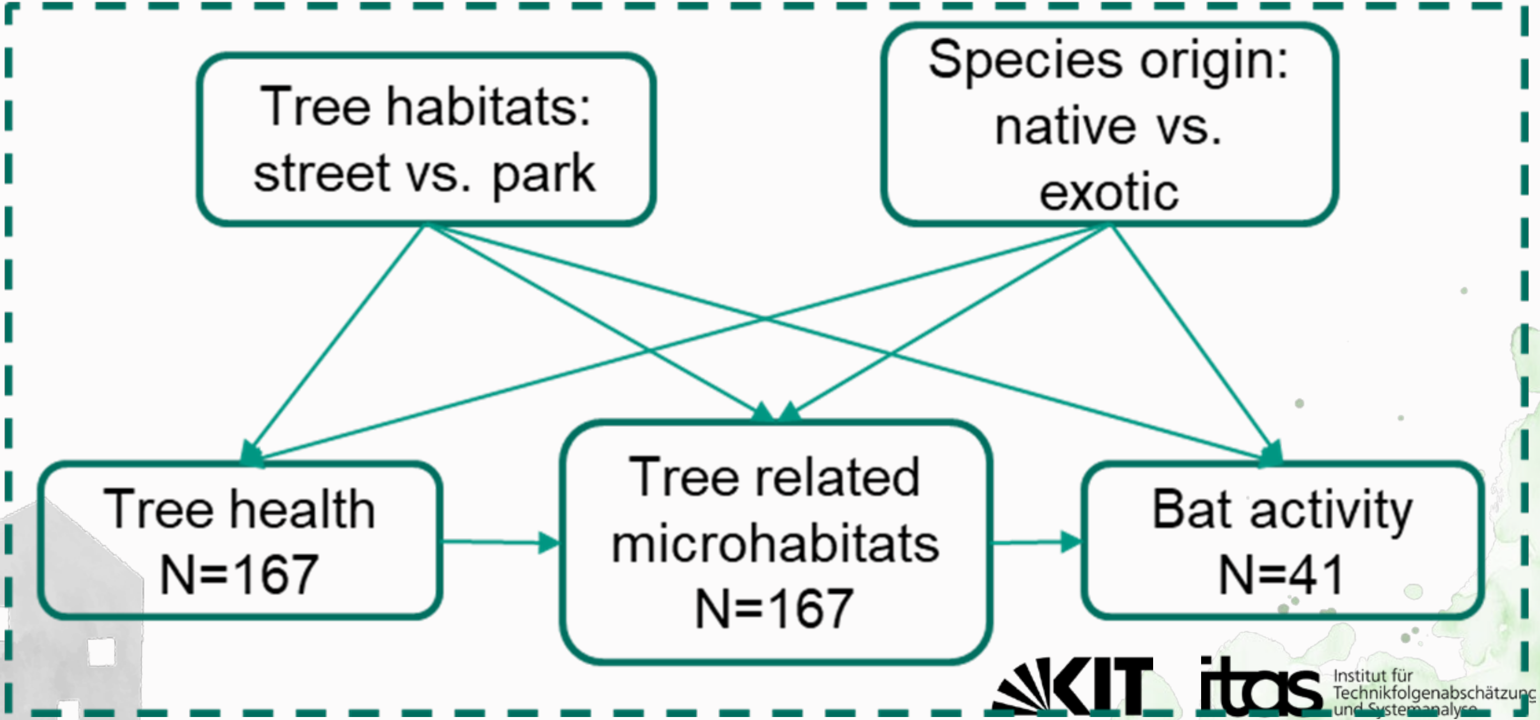
Tree microhabitats, bats, and health symptoms: Dataset 1



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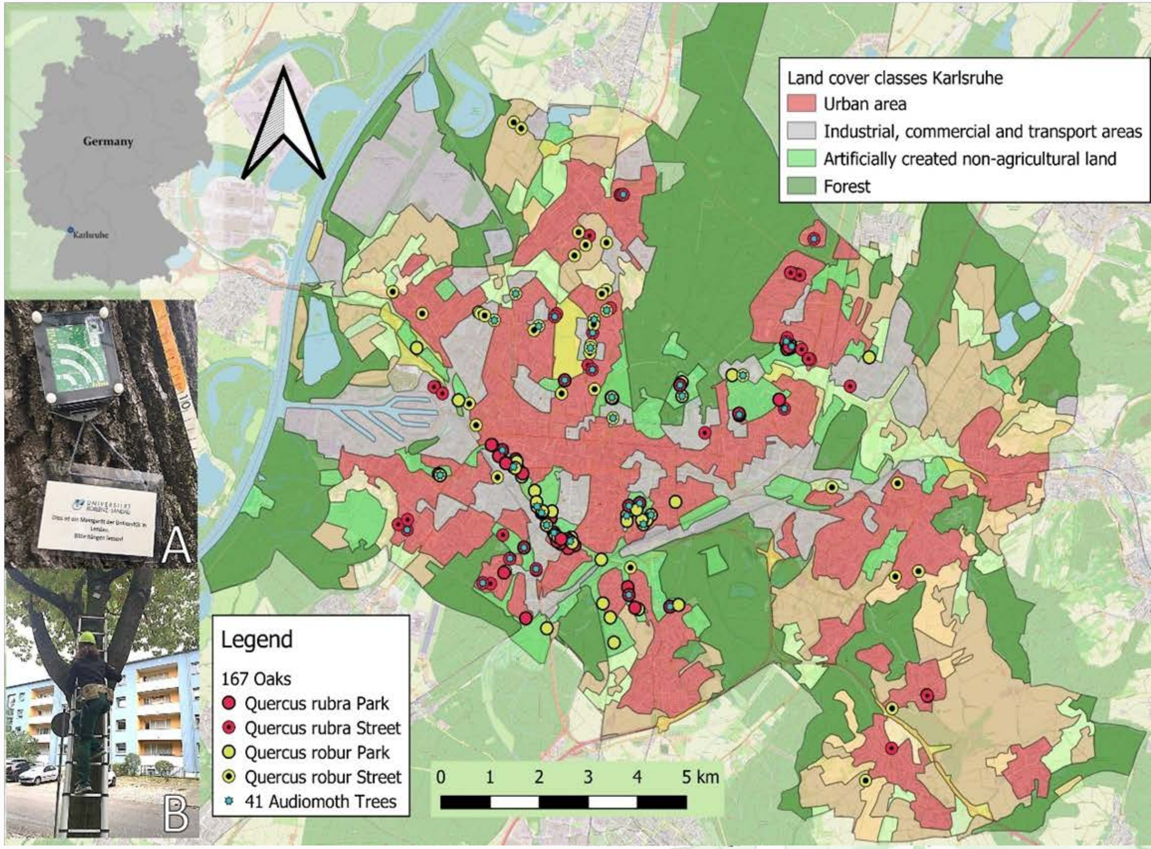
Tree microhabitats, bats, and health symptoms: Dataset 1

Trees selection for health and microhabitats

- Diameter at 1.3 m height/DBH > 20CM
- Random selected
- 42 trees for each category
  - street vs. park
  - native vs. non-native
  - one tree died during field data colleciton

Trees selection for bat activity

- DBH > 50CM
- Random selected within 167 trees
- 10 trees for each category
  - street vs. park
  - native vs. non-native
  - and 5 more



Tree microhabitats, bats, and health symptoms: Dataset 1

Dendrometry Variables
Tree ID
Street/Park tree
Species
DBH
Number of cut branches
Dieback
Total height
Height to crown top
Height to crown base
Crown width
Crown missing
Impervious beneath canopy
Shrub cover beneath canopy
Crown Light Exposure (CLE)
Crown openness %

Tree health variables	
Tree stress	Dieback
	Epicormic sprouts
	Wilted foliage
	Abiotic stress
	Biotic stress
	Tree stress notes
	Tree stress area
Signs and symptoms of foliage and twigs	Defoliation
	Discoloured foliage
	Abnormal foliage
	Insect signs
	Foliage and twigs area
	Foliage and twigs notes
Signs and symptoms of branches and bole	BB insect signs
	Insect presence
	Disease signs
	Problem location
	Loose bark
	Branch and bole notes

Epicormic shoots

Crown dieback

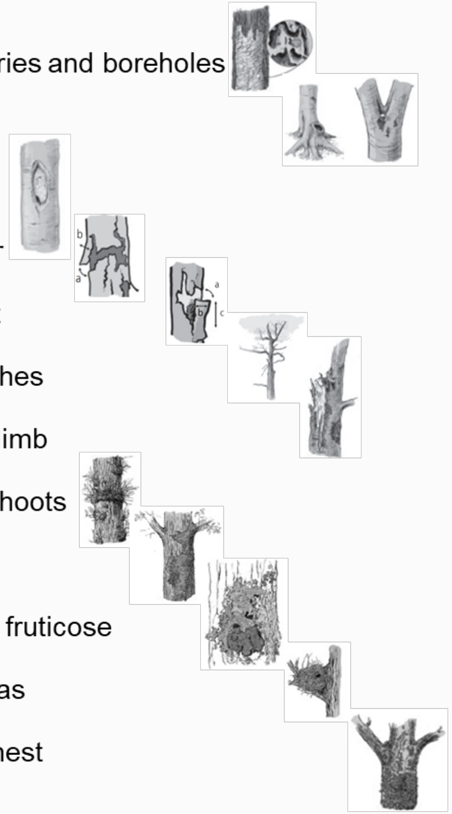
Defoliation

Discoloured foliage

Four of 11 observed tree health symptoms were involved in the calculation of tree health score

Tree microhabitats, bats, and health symptoms: Dataset 1

- Insect galleries and boreholes
- Dendrotelm
- Bark loss
- Bark shelter
- Bark pocket
- Dead branches
- Remaining limb
- Epicormic shoots
- Bryophytes
- Foliose and fruticose
- Ivy and lianas
- Vertebrate nest



- Microhabitat score/abundance:

Normalized data of all microhabitat variables, which occurred on at least 20 trees

- Microhabitat richness:

counting of microhabitat types on each tree

Twelve of 32 observed tree related microhabitats were involved in the analysis

Larrieu et al. (2018) and Kraus,D. et al. (2016)

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Tree microhabitats, bats, and health symptoms: Dataset 1

- Experimental equipment: AudioMoth acoustic recorders
- Attach tree height: 4m
- Recording time: 6:30 pm - 9:30 am, 2 October to 5 October 2020
- Sampling rate: 256 kHz, Gain: Medium

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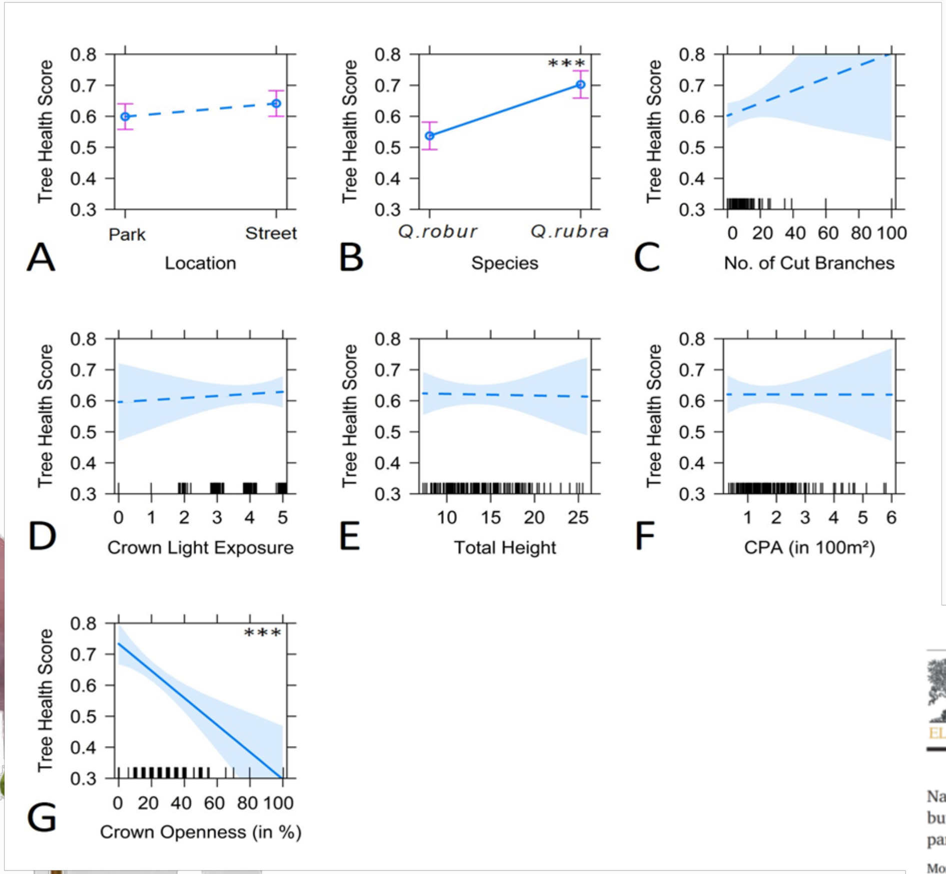
Red oaks had better health (lower crown die-back, defoliation, and discoloration) than pedunculate oaks.




Science of the Total Environment 853 (2022) 158603
Contents lists available at ScienceDirect
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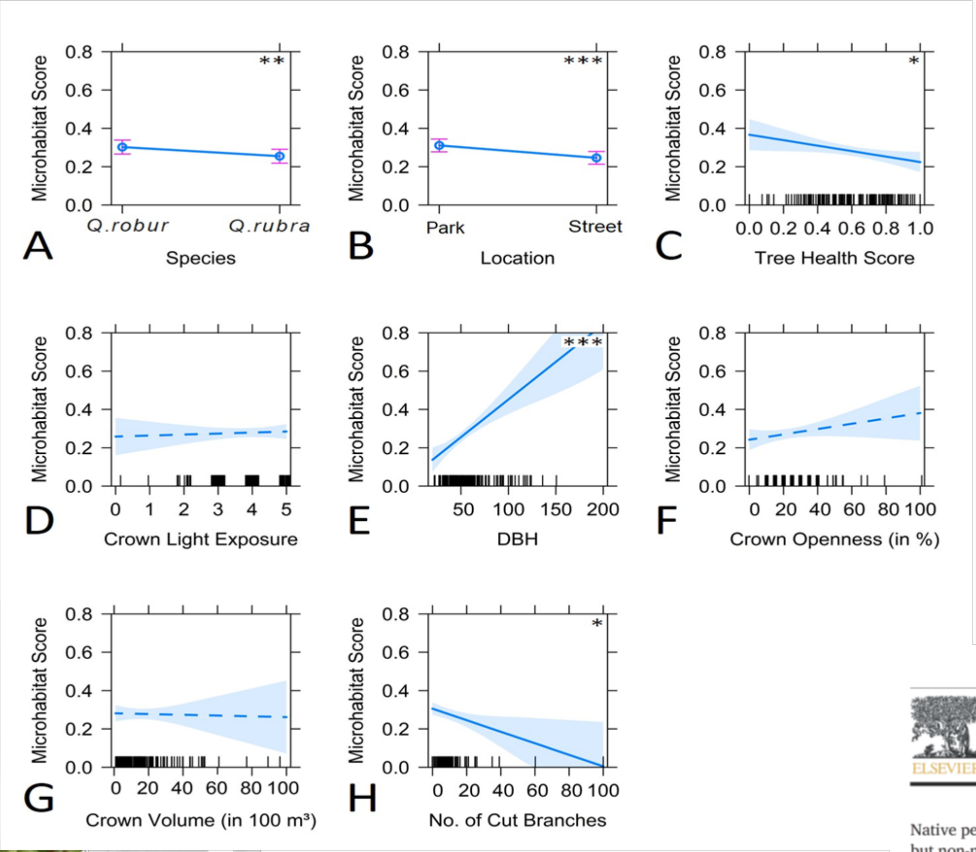
Native pedunculate oaks support more biodiversity than non-native oaks, but non-native oaks are healthier than native oaks: A study on street and park trees of a city

Monika Laux [a], Hailiang Lv [a,b,*], Martin H. Entling [c], Jens Schirmel [c], Aditya Narang [c], Mario Köhler [d], Somidh Saha [a,e]

But diversity and abundance of microhabitats are higher in native pedunculate oaks than exotic red oaks



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Native pedunculate oaks support more biodiversity than non-native oaks, but non-native oaks are healthier than native oaks: A study on street and park trees of a city

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Bat activities recorded in AudioMoth survey

Bat group	Bat species (English name)	Active minutes	% of sites with group
***Myotis* group**		**72**	**12.2**
	Myotis daubentonii (Daubenton's bat)	72	
Nyctaloid group		**623**	**65.9**
	Nyctalus leisleri (Lesser noctule)	51	
	Nyctalus noctula (Common noctule)	567	
	Eptesicus serotinus (Serotine bat)	5	
***Pipistrellus* group**		**10,287**	**100.0**
	Pipistrellus kuhlii (Kuhl's pipistrelle) / *Pipistrellus nathusii* (Nathusius's pipistrelle)	576	
	Pipistrellus pipistrellus (Common pipistrelle)	9,388	
	Pipistrellus pygmaeus (Soprano pipistrelle)	323	
***Plecotus* group**		**356**	**48.8**
	Plecotus cf. auritus (Brown long eared bat)	356	
Bats (total)		**11,338**	

- Bat activity: number of minutes with calls of each species.
- Acoustically similar bats were grouped to avoid misidentification

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Bat activities near native and exotic oak trees at street and park

***Pipistrellus* bats:**
prefer parks but not differentiate species

Brown long-eared bats (*Plecotus*):
prefer native oaks
prefer parks
prefer trees with fork split, sunscald damage and woodpecker holes

Noctule bats (Nyctalus):
neither differentiate between trees nor between habitats

Image sources: Pixabay and Google

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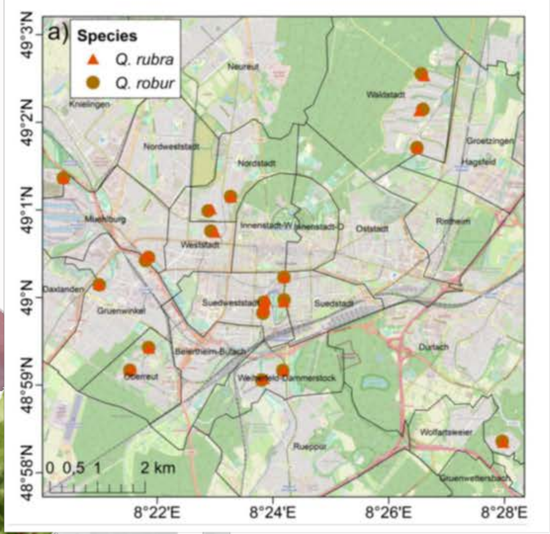
Tree ring growth, response to drought and internal trunk damage (Dataset 2)

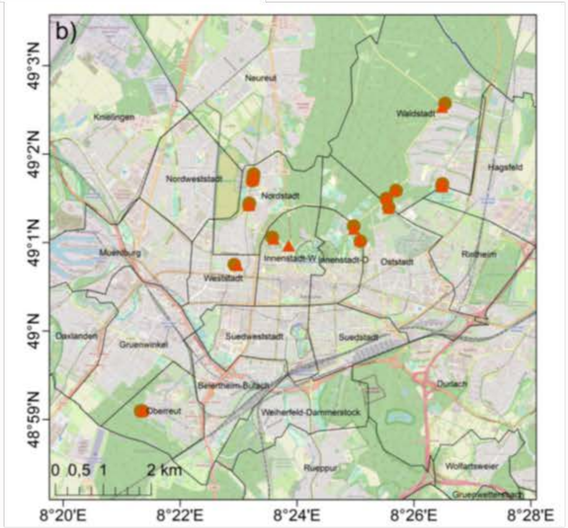
Tree ring research and sonic impulse tomography were used in this study in addition to standard dendrometric assessment.

Tree ring growth, response to drought and internal trunk damage (Dataset 2)

	Quercus robur		*Quercus rubra*		
	vit. class 0	vit. class > 0	vit. class 0	vit. class > 0	**Total**
Park	8	12	8	12	40
Street	8	12	8	12	40
Total	16	24	16	24	**80**



Parks



Streets

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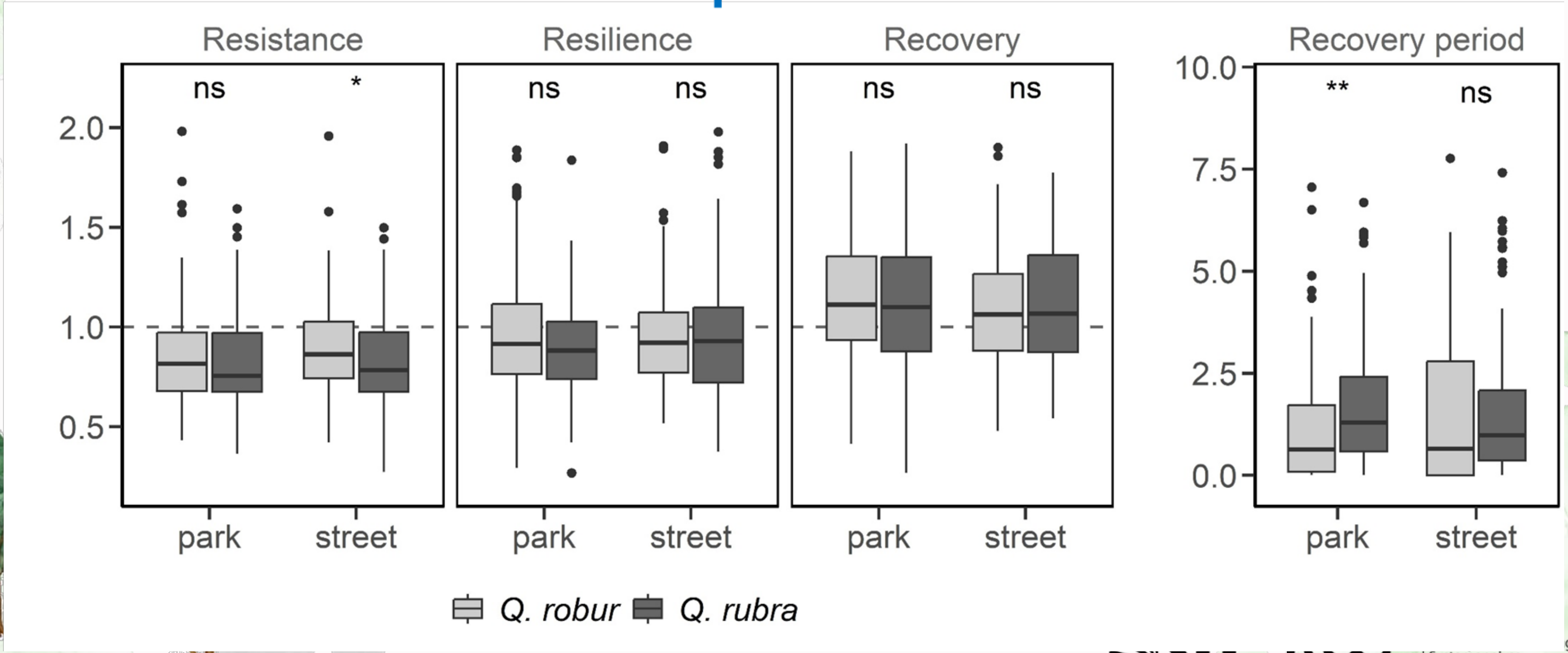
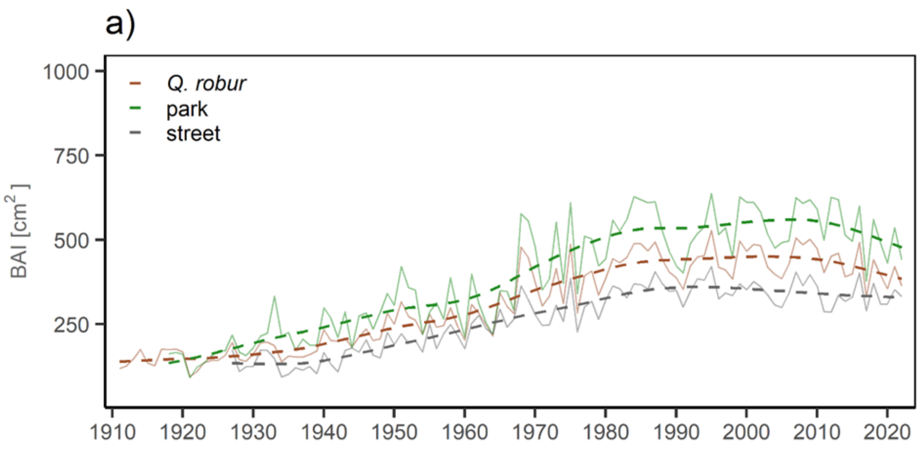
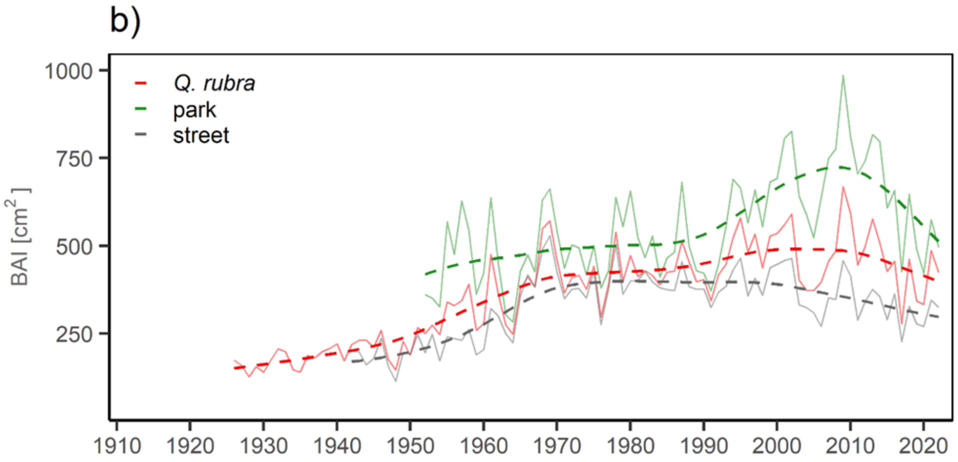
Pedunculate oak had higher resistance to drought in the street and lower recovery time from drought stress in parks



Pedunculate oak grew slower than red oak but growth of red oaks fell after 60 years!





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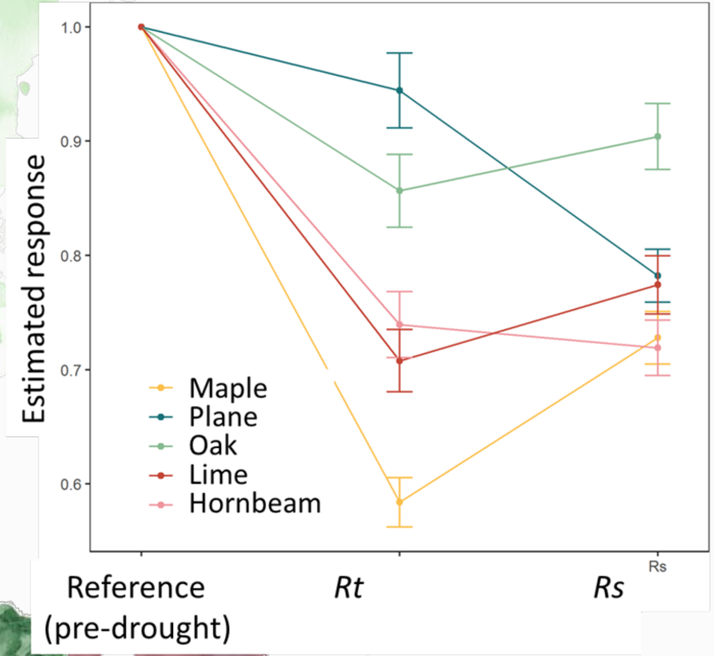
Growth response differs between species



Plane trees have high resistance but low resilience. Native oaks have both high resistance and resilience.

Trees
https://doi.org/10.1007/s00468-022-02294-0

ORIGINAL ARTICLE

Check for updates

Drought tolerance differs between urban tree species but is not affected by the intensity of traffic pollution

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Working hypotheses revisited

In Karlsruhe city, exotic *Q.rubra* (red oak) trees have better performance than native Q. robur (pedunculate oak) trees in:

- **H1) radial growth; accepted (at least in first 70 years)**
- **H2) tolerance to drought; rejected (warrants field ecophysiological study)**
- **H3) internal trunk defect; rejected (warrants root decay and fungi study)**
- **H4) health symptoms such as lower crown die-back; accepted (but can be result of management)**
- **H5) Microhabitat provisions and bat diversity; rejected**
- **H6), and those responses varied between growing environments (park vs. street) and other factors: partially accepted (tree size, park vs. street, soil physical properties, and tree pruning intensity are important, warrants long-term monitoring)**

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Synthesis

Key take homes

1. Poor vitality of solitary and stand forming trees
2. Trade-offs between supporting and regulating ecosystem services
3. Species origin, functional trait, irrigation, local soil, and solar irradiation are very important to consider
4. Healthy and high proportion of leaf area is key for cooling

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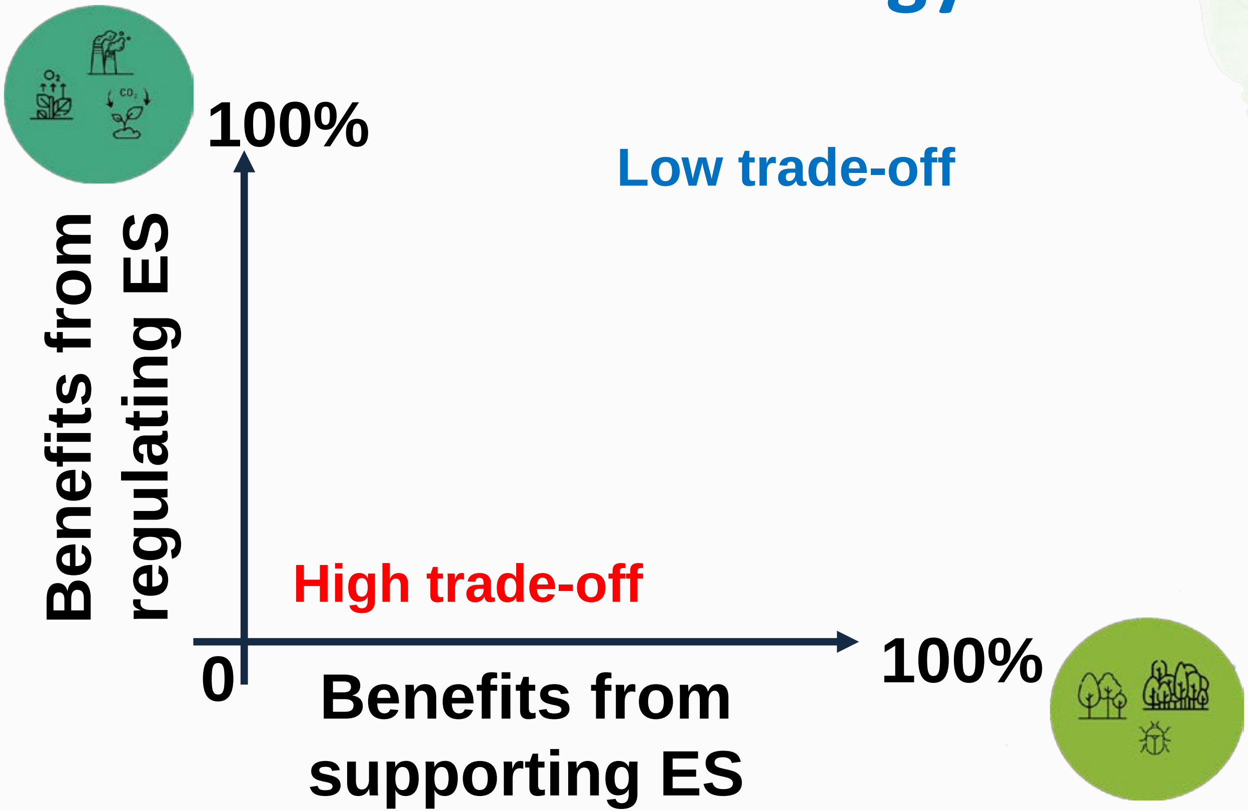
What is a trade-off in ecology?

- It is a spatial, statistical, and temporal pattern of relationships between two or more variables when gain in one variable can result in loss in another.
- In nature, it is a very normal thing.
- It becomes a concern in anthropocentric systems when humans want benefits or services from multiple biophysical variables simultaneously and indefinitely.
- Scientists and managers often want to understand these patterns in detail. For example, understanding processes and ramifications of trade-offs can contribute to tuning management so that a win-win situation can be reached.

What is a trade-off in ecology?



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How to reduce trade-offs

1. Increase tree species diversity in streets
2. Increase flora and fauna diversity in parks and gardens
3. Increase urban green space cover
4. Improve and modernize tree inspection and tree care
5. Bring complexity and innovation to landscape design
6. Increase awareness, involve citizens and stakeholders

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Thank you