The role of trees and greenspaces in mitigating urban heat islands

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Member of:
TDAG (Trees and Design Action Group)

Scene setting

Land Regeneration

Remediation

Species selection
Process

Urban Trees and Greenspace

Ecosystem service provision

Quantification and valuation

= Decision making

i-Tree

Provisioning	**Regulating**	Supporting	Cultural
	Climate regulation Air pollution Storm-water capture		

Urban cooling by trees and GS

1. Cooling by one large Greenspace (Kensington Gardens)
2. Cooling by greenspaces of various sizes
3. A study into pan-city cooling
4. ‘Research Notes’
5. Cooling by street trees
6. Valuing cooling
7. Species selection for cooling

- (a little bonus for you)

Forest Research

Urban Heat Island abatement by greenspaces

A study of Kensington gardens

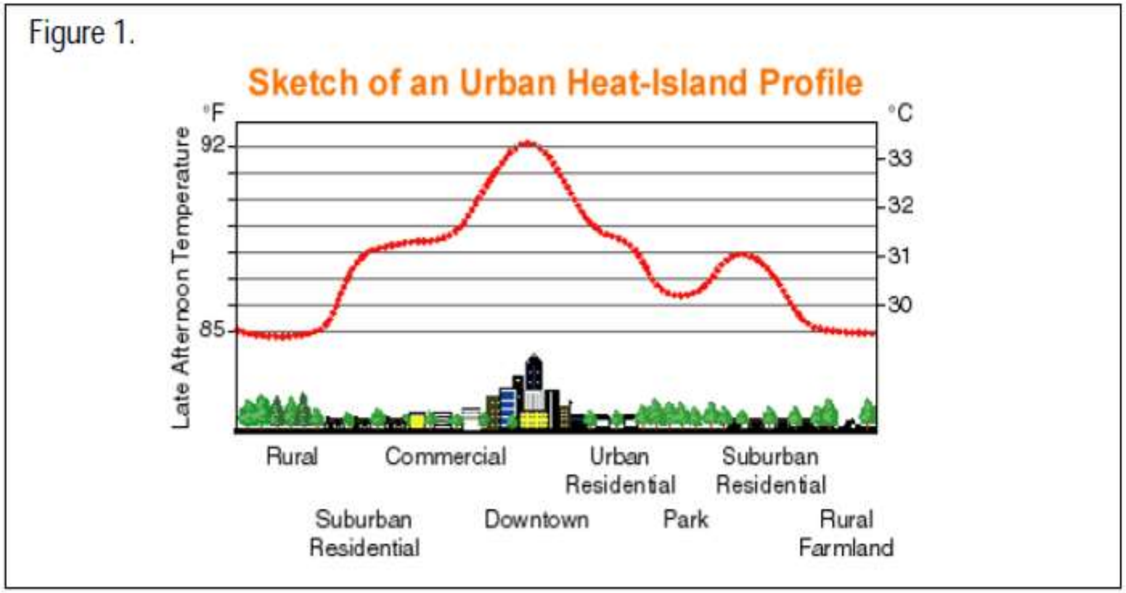
The Urban Heat Island (UHI)

"higher mean average temperature in cities than surrounding countryside"

$$UHI = Temp_{(Urban)} - Temp_{(Rural)}$$

First reported by Luke Howard in…

1820



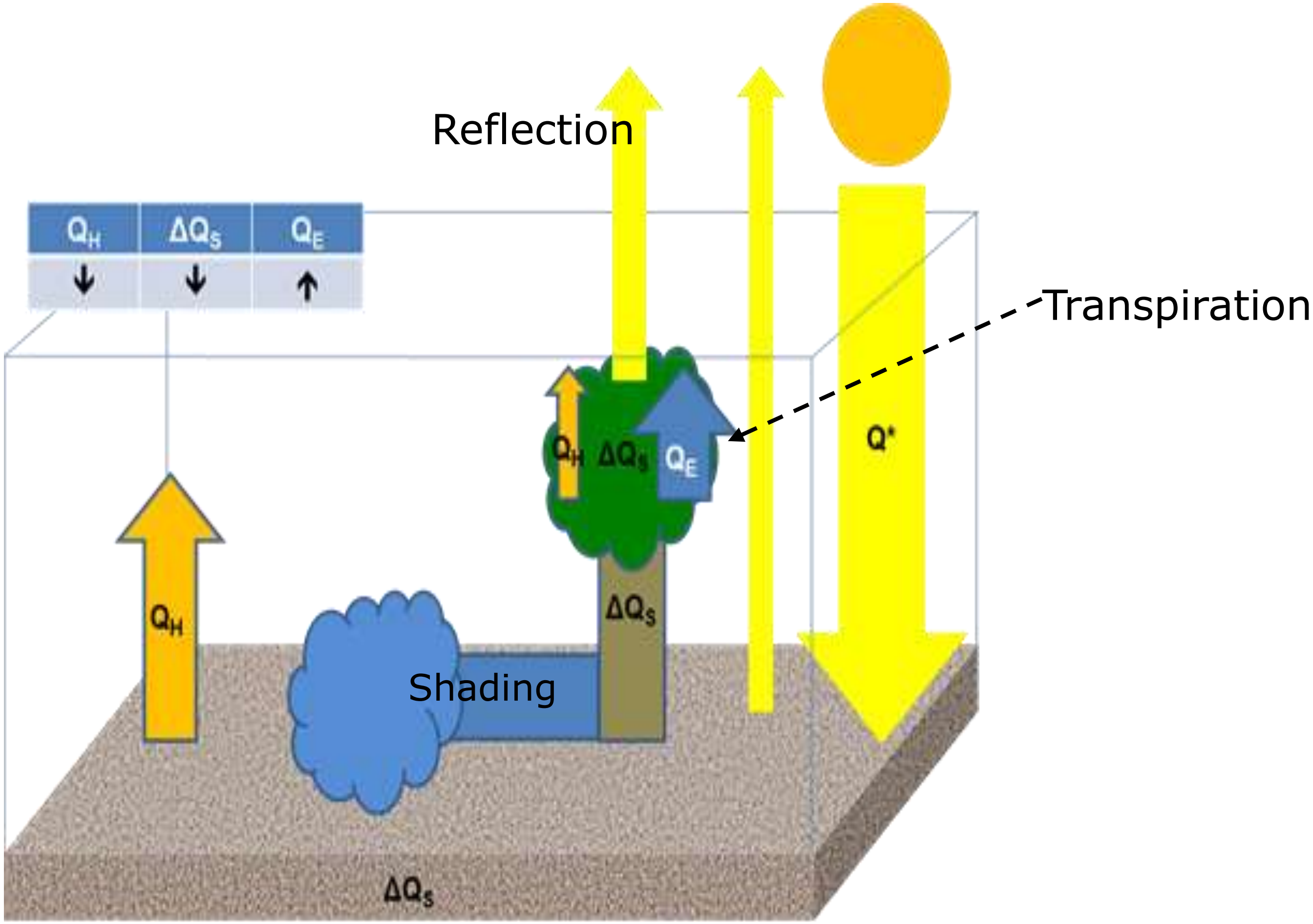
Ref: GLA (2006) London's urban heat island: A summary for decision makers

Introduction (cont.)

Nice and warm, so why the fuss…

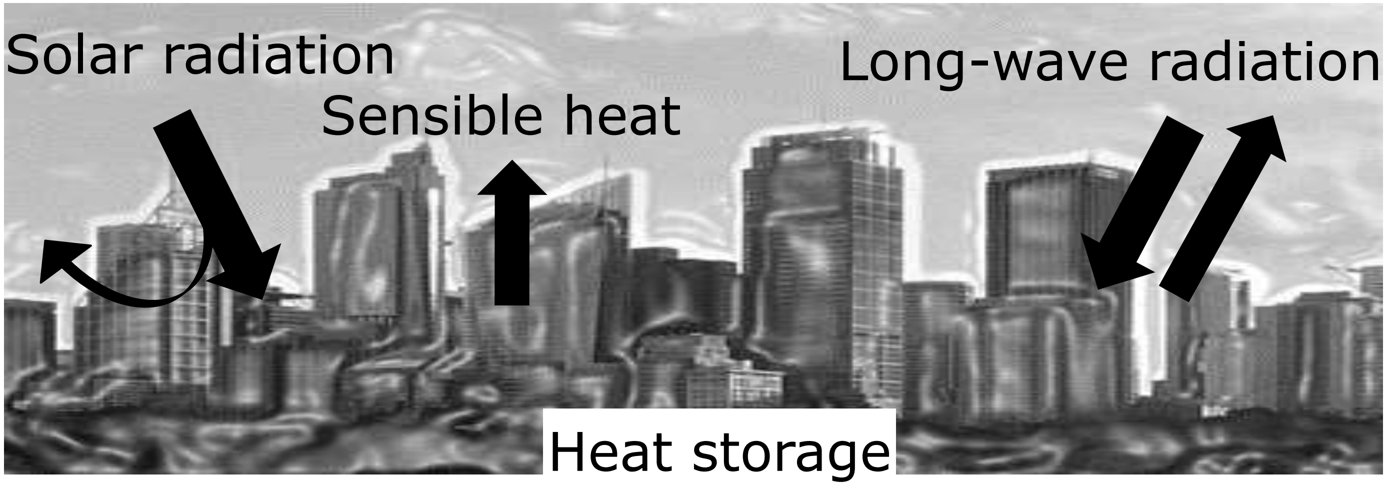
- UHI intensity can be as much as 9°C (may be more)
- There is a direct and significant impact of heat on human health…
  - ~ 1,100 heat-related deaths and 100,000 hospital patient-days per year in the UK
  - …plus 10s to 100s more deaths per heat wave
    - 30th June to 2nd July 2009 = 299 excess deaths in England
- Combined effect of climate change and UHI
- Climate change scenarios are for rural setting
- Multiple cooling mechanisms from vegetation; these are additive and is significant enough to impact at the city scale

Transpiration > Reflection of solar radiation > Shading

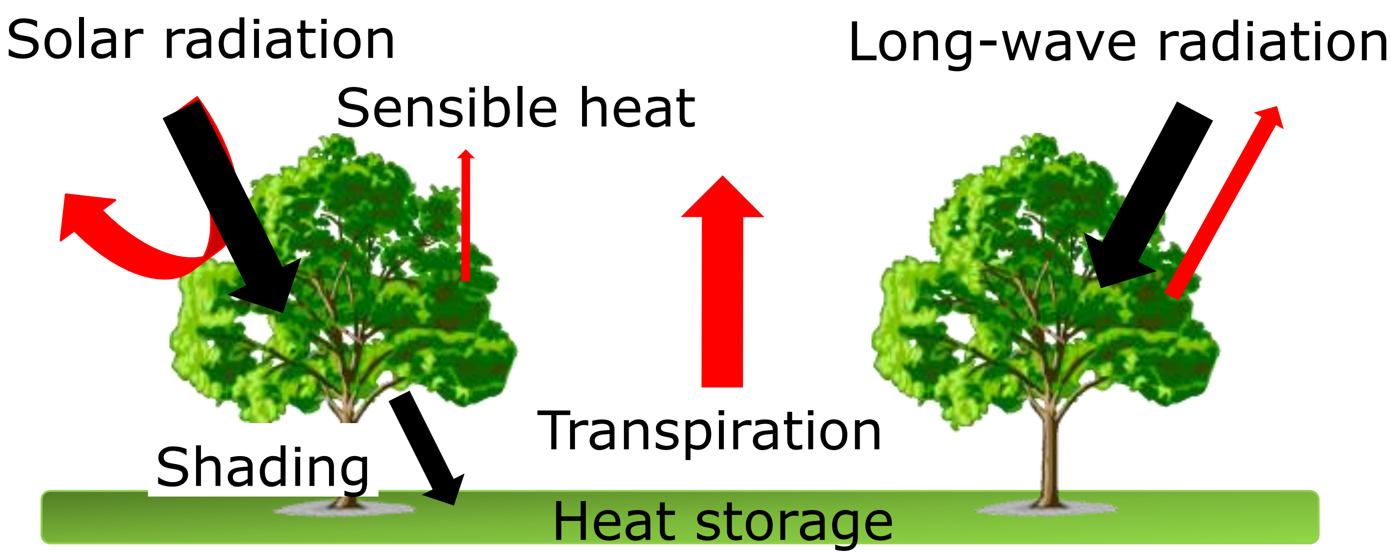


Key: Q* = Solar radiation; QF = Anthropogenic heat; QH = Sensible heat flux (heated air); QE = Latent heat flux; (energy used in evaporating or transpiring water); ΔQS = Heat storage within the environment; ΔQA = Net advective (horizontal) heat flux

One solution



Green infrastructure can mitigate UHI



Methodology

Road Transect 1:

Queensway

Road Transect 2:

Gloucester Terrace

Key:

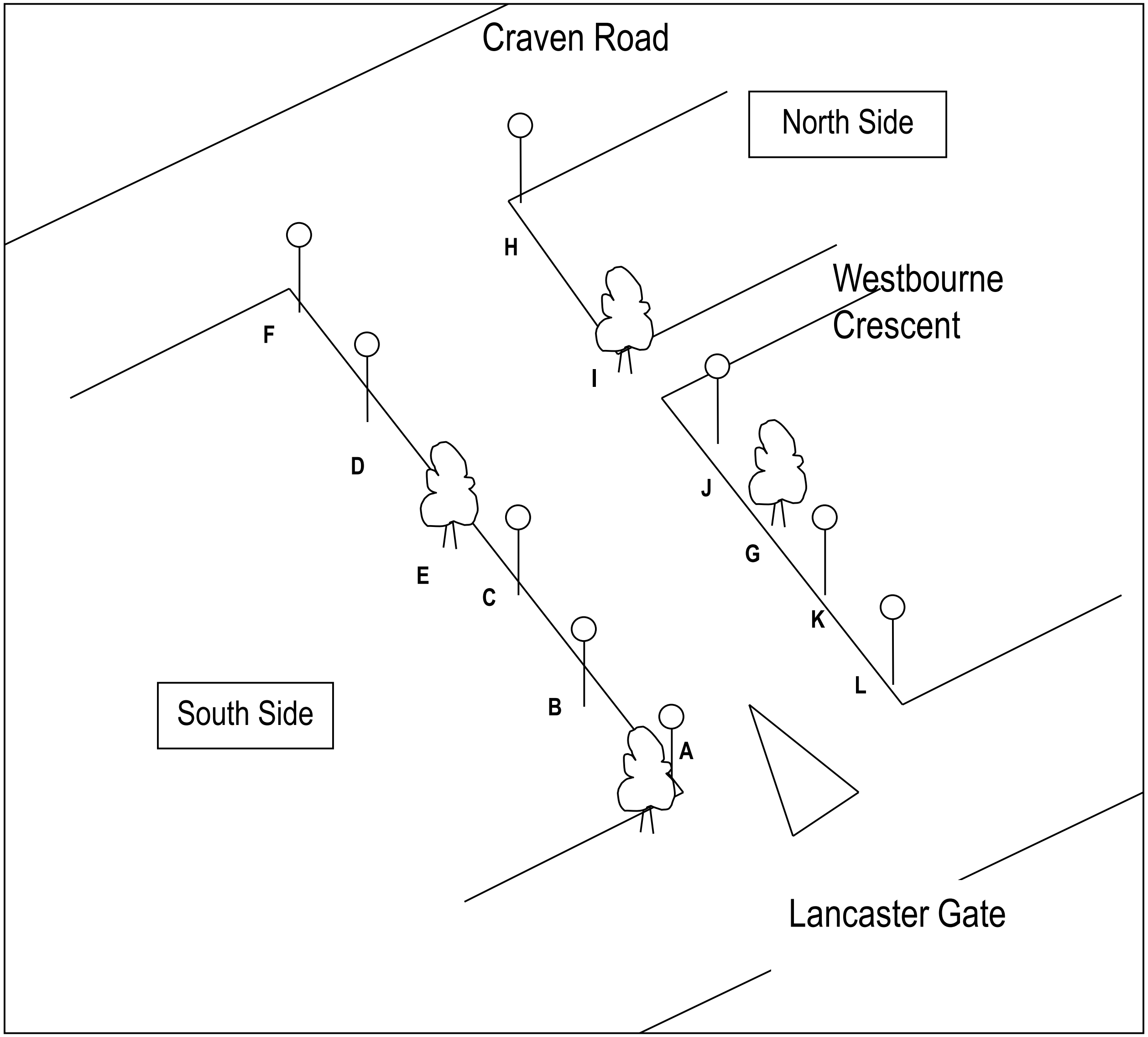
O = open space

G = grass

T = tree

Methodology (cont.)

Sensor Locations along Gloucester Terrace Transect



Key:

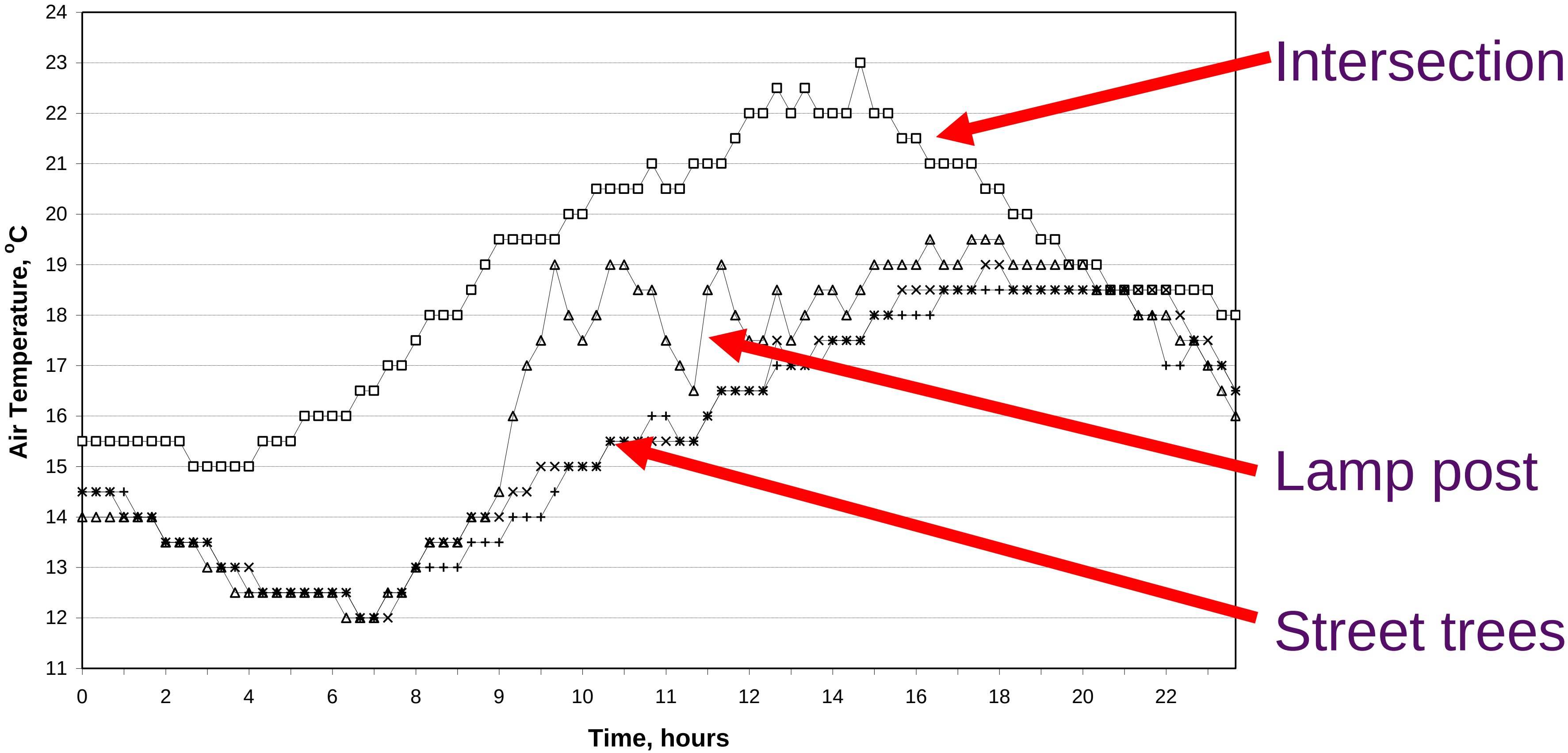
South: A, B, C, D, E, F,
North: G, H, I, J, K, L

Trees: A, E, G, I
Lamp posts: B, C, D, F, H, J, K, L

Intersections: A, F, G, L

Methodology (cont.)

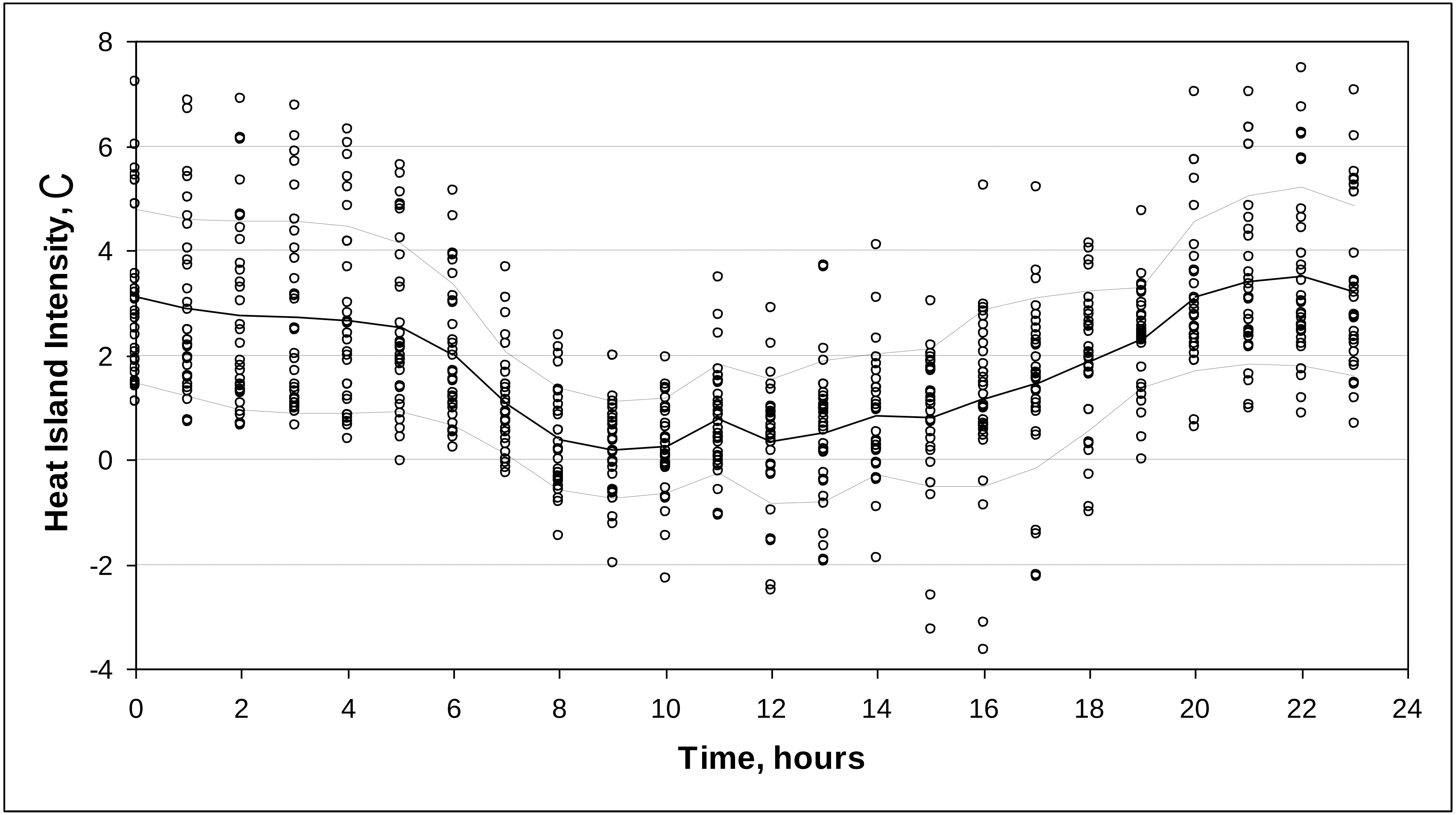
Comparison of air temperatures (four locations within Gloucester Terrace; one 24-hour period)



Results

- Streets significantly warmer than the average temperature across Kensington Gardens
- Hard-standing area (only) of Kensington Gardens not significantly warmer than Streets
- Grassed area of Kensington Gardens significantly warmer than the tree-lined area in August and September
- Street canyons not significantly warmer than intersections
- Air temperature below street tree canopies not significantly cooler than lamp-post (24hr mean)
- $p<0.05$ or $p<0.01$

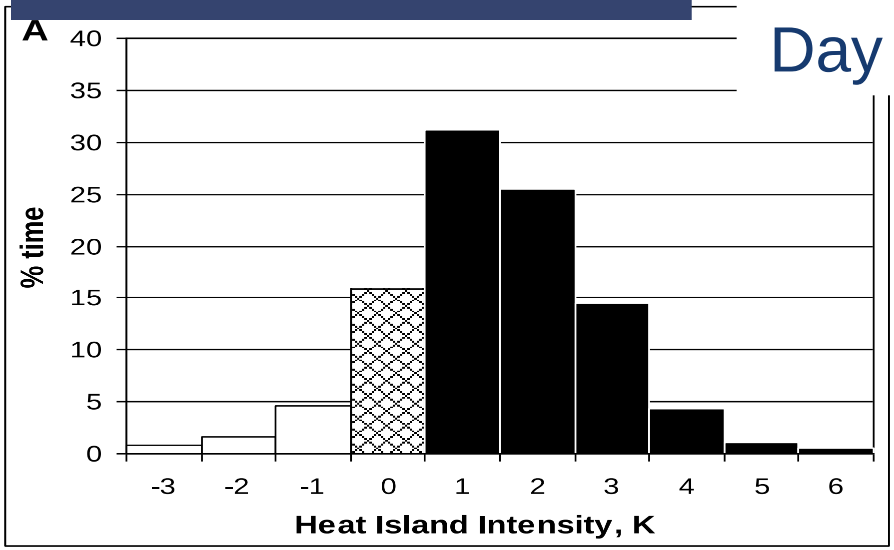
Variation in heat island intensity at mid-point along Gloucester Terrace transect (August)

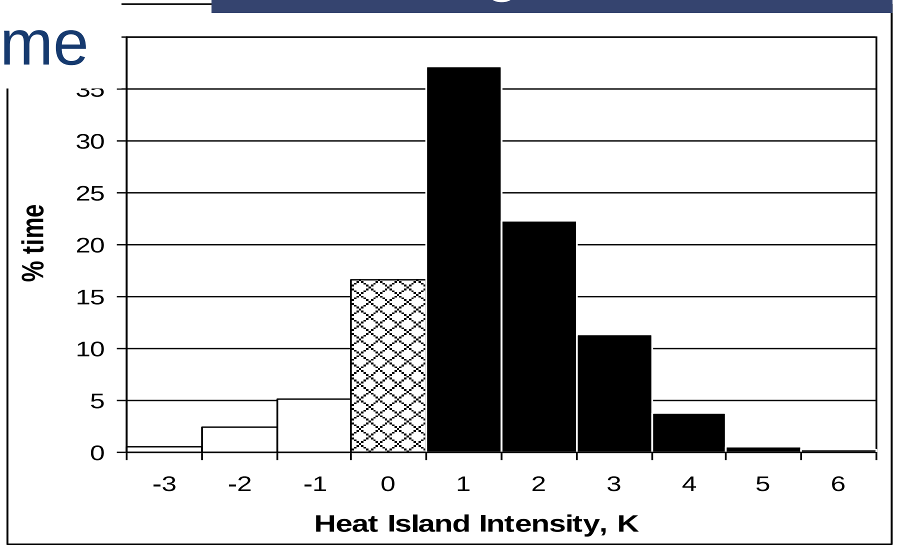


Frequency Distribution plots…

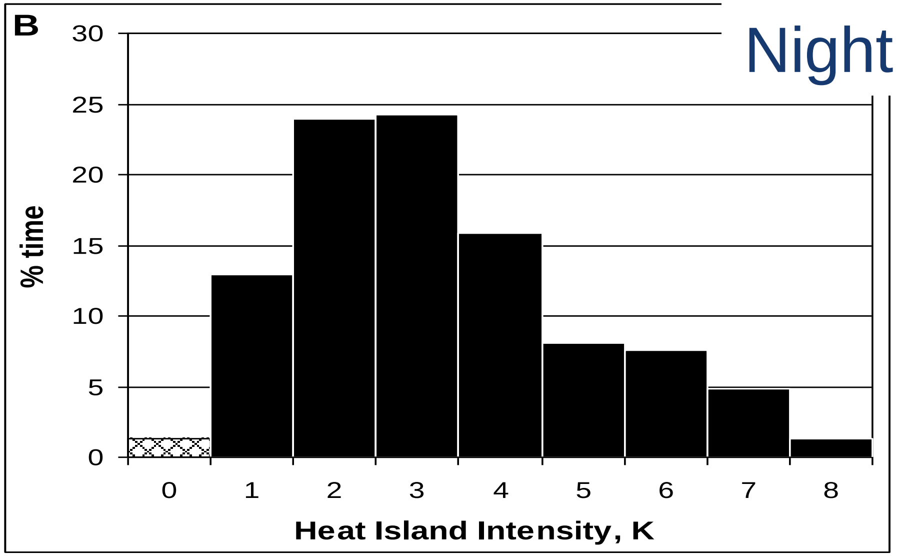
Gloucester Terrace | Kensington Gardens

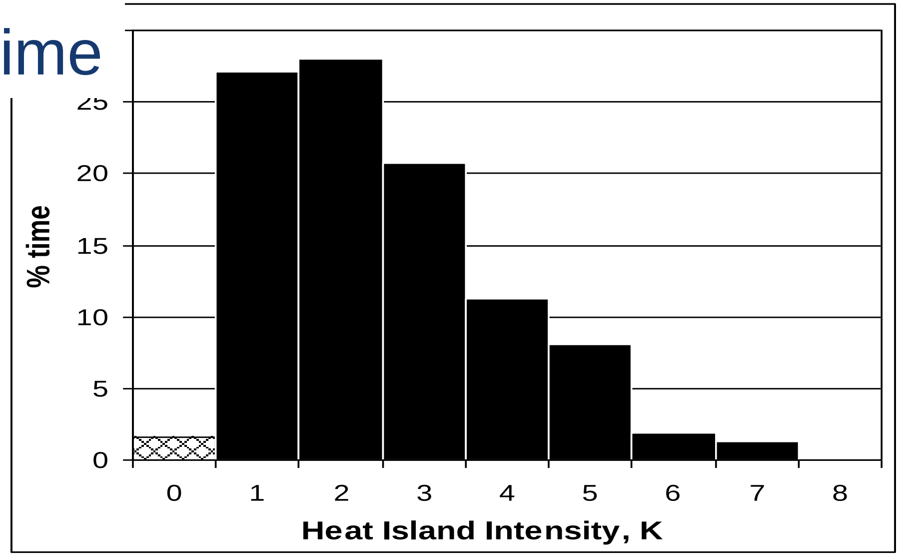
Day time





Night time





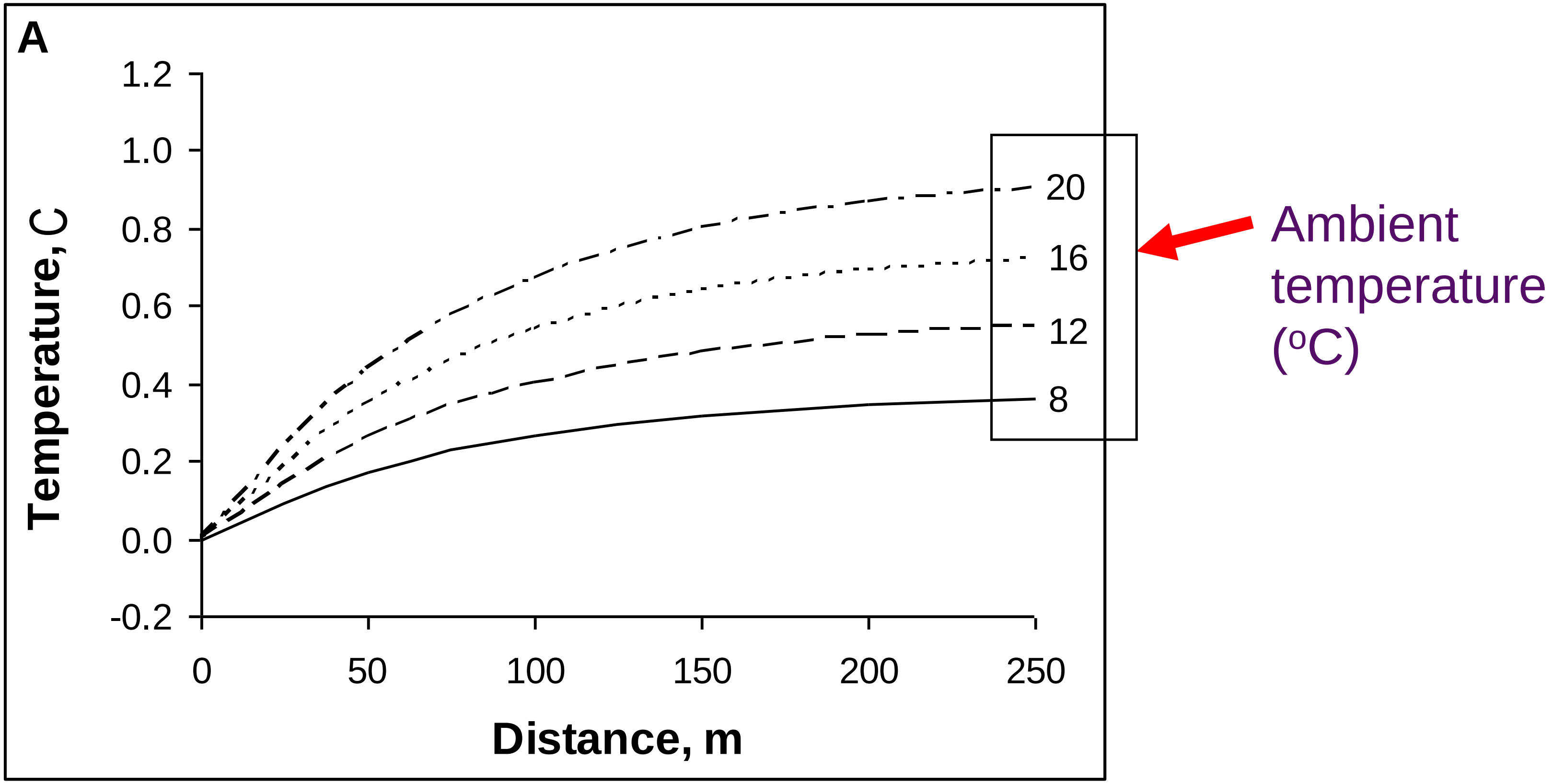
Analysis of heat island intensity at various locations across London

- Max and Min's are the largest and smallest hourly UHI value observed in a month
- Mean values are for the month

Location	Heat Island Intensity, C								
	August			September			October		
	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min
St James'	6.1	1.2	-5.4	6.3	1.2	-2.1	8.7	1.3	-2.1
Kensington Gardens	6.6	1.4	-3.4	7.5	1.5	-2.1	8.6	1.5	-2.3
Gloucester Terrace	7.5	1.8	-3.6	9.1	2.0	-2.2	10.5	2.1	-2.2
Queensway	7.9	2.1	-4.1	9.2	2.2	-2.1	10.5	2.2	-2.2
Rush Green	6.8	2.2	-2.8	6.1	2.1	-1.8	4.5	1.5	-1.4

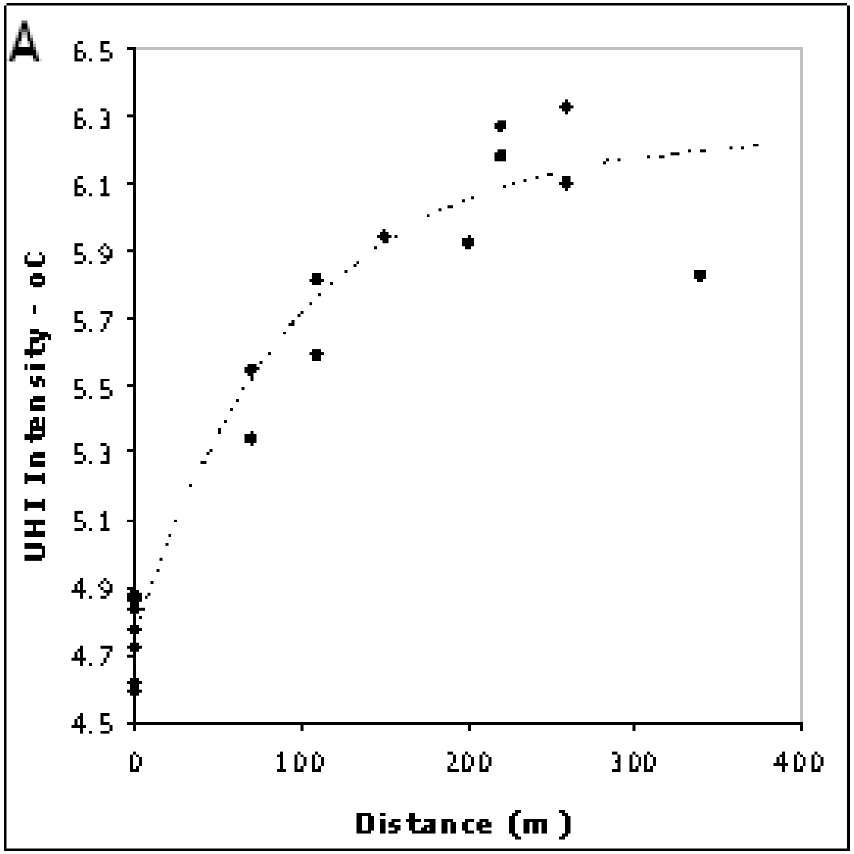
Results

Modelled temperature gains with increased distance from Kensington Gardens



Modelling used mean under street tree heat island values relative to the under tree temperatures in Kensington Gardens

Results 2011

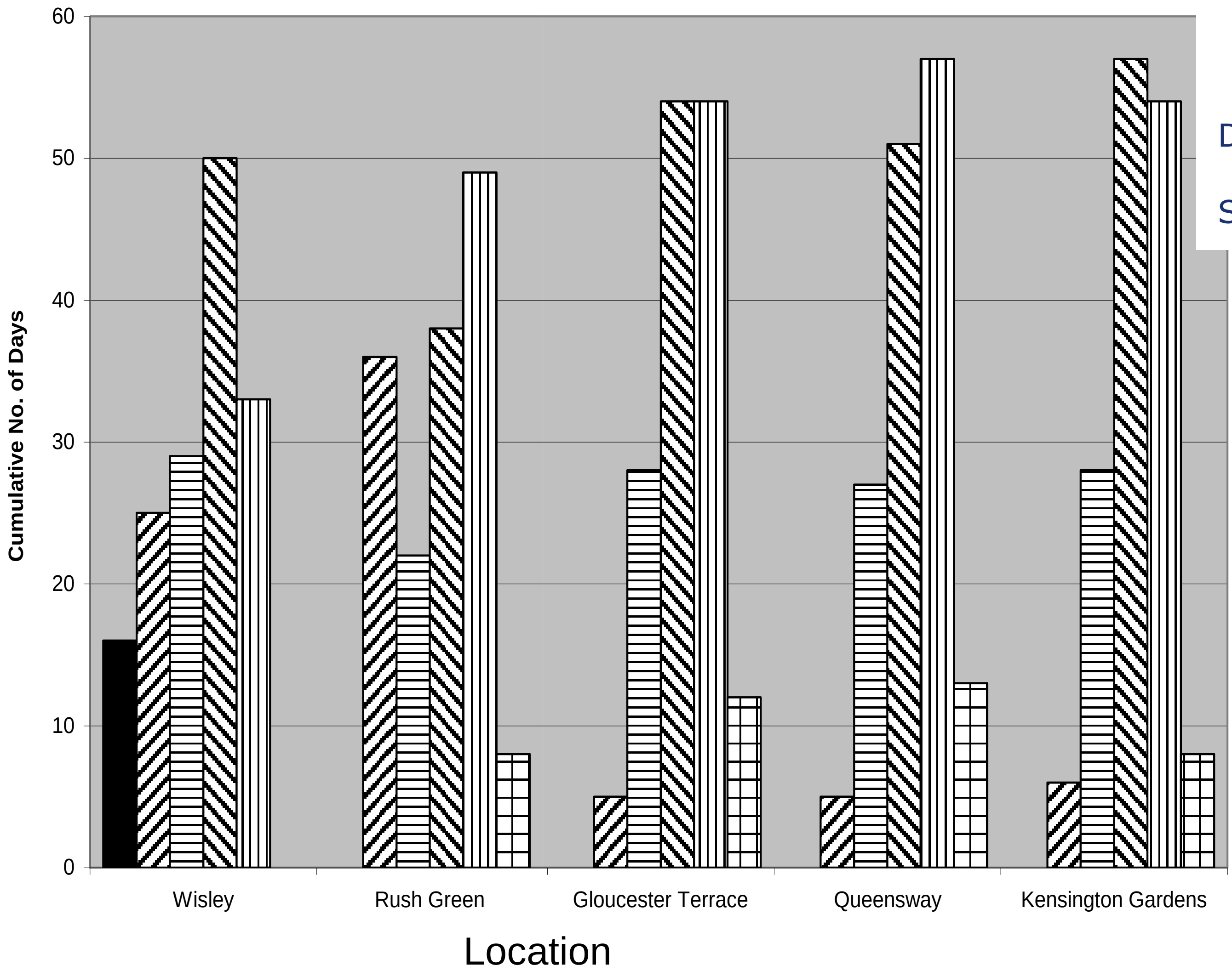


Relationship between urban heat island intensity and increased distance from Kensington Gardens on 9 August

Park cooled the transect when cooling was most needed, on warm calm nights

Cooling of up to 4°C over 440 m distance from the park was observed on single nights

Frequency distribution of daily mean average temperatures



Key:
Black bars <0°C
Up-diag. 0-5°C
Horizantals 5-10°C
Down-diag. 10-15°C
Verticals 15-20°C
Square hatch >20°C

Implications

- Urban dwellers are exposed to warmer temperatures for longer periods than people living in the countryside
- It is cooler close to a large greenspace than [say] 200-300m away; street trees offer some protection too
- Impact of cooling by large greenspaces may be lowest when needed the most
- Dormancy and frosting of urban trees/ green-spaces is slight and (possibly) decreasing
- Forecast climate = increasing social and environmental pressures on greenspaces (climate and biotic pressures)

Future Work

More questions

- Impact of… …on cooling effect
  - greenspace size
  - greenspace design (relative proportions of hard surfaces, grass and trees)

- Cooling boundary: what governs…
  - Shape
  - Size
  - Permanence
  - Penetration into surrounding areas (role of street canyons vs. buildings as barriers to air movement)

Future Work

- Cooling by vegetation vs. thermal comfort
- Valuing the cooling effect of
  - street trees
  - green spaces
  - green infrastructure
- Species selection for optimised cooling (given urban setting, climate change)
- How to position street trees for optimal cooling

Forest Research

Urban Heat Island abatement by greenspaces

A study of Cooling by Greenspaces of various sizes

The role of greenspaces in mitigating London's UHI

In 2011

- Air temperatures measured in one of central London's large greenspaces and in an adjacent street
- Aiming to determine the extent to which the greenspace reduces UHI

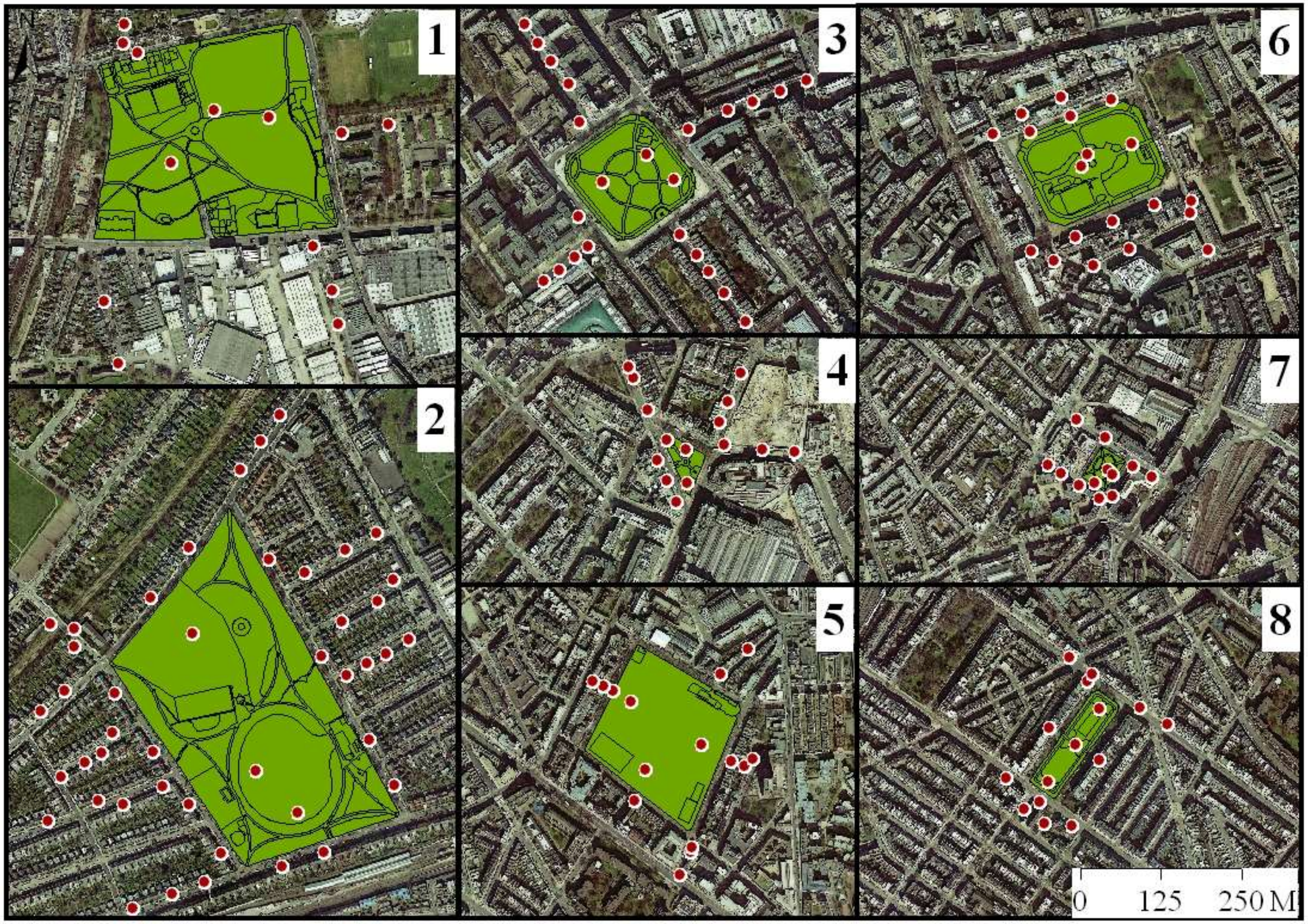
Doick et al., 2014. Science of the Total Environment 493: 662–671

In 2012

- Air temperatures measured in and around eight London greenspaces, with areas ranging from 0.2 to 12.1 ha
- Aiming to define the relationship between cooling extent and the size of greenspace

Vaz Monteiro et al., 2016. Urban Forestry & Urban Greening 16: 160–169

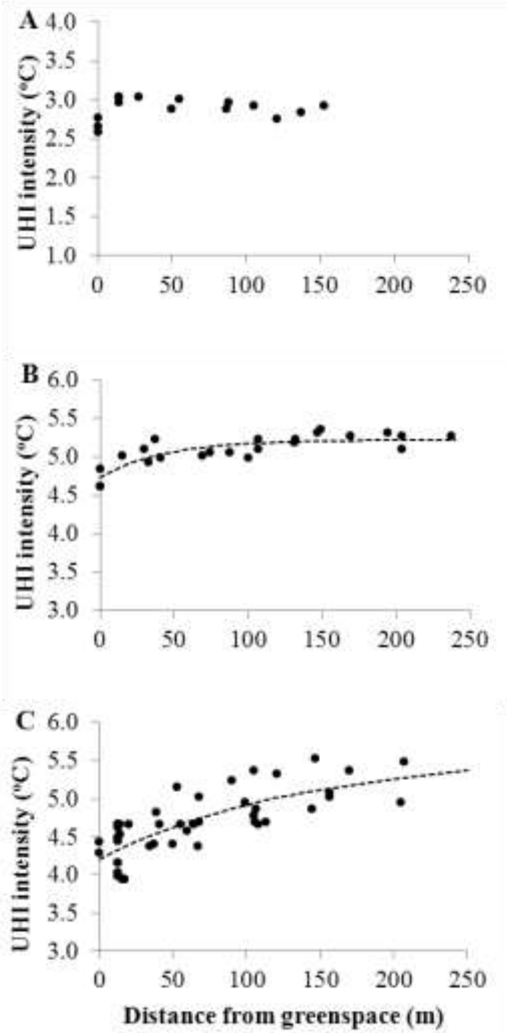
Study areas 2012



Key: 1. Acton Park, 2. Queen's Park, 3. Russell Square, 4. Grosvenor Gardens, 5. Vincent Square, 6. Lincoln's Inn Fields, 7. Ebury Square Gardens and 8. Warwick Square (© Crown copyright and database right [2015] Ordnance Survey [100021242])

Results 2012

Modelling of cooling extent was statistically valid only on calm warm nights (≥ 10°C and wind speed ≤ 3 m/s)



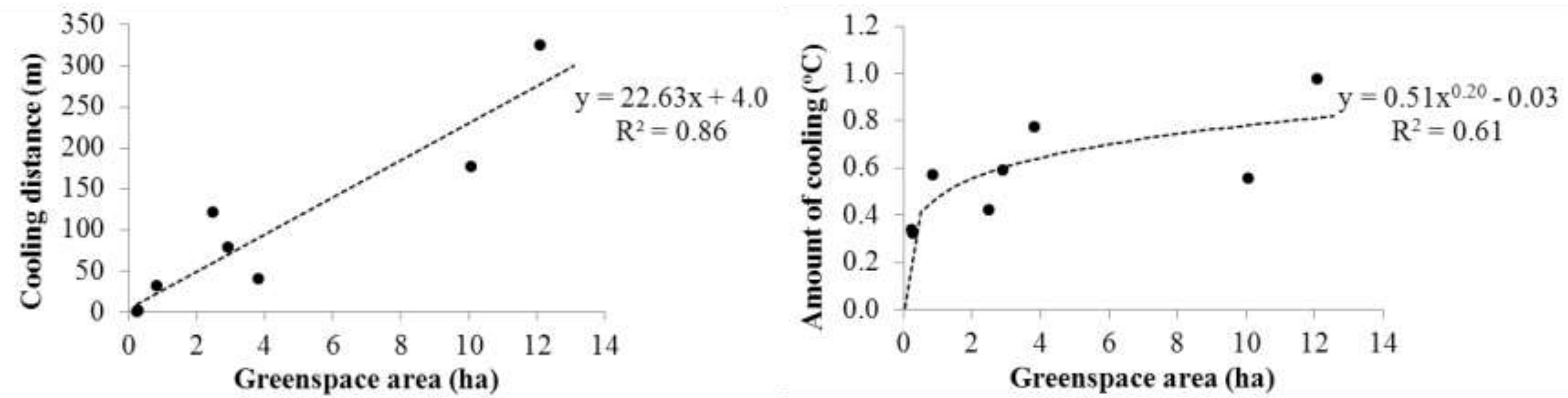
Very small greenspaces (area <0.5 ha) did not affect the air temperatures of their surrounding areas

Small greenspaces (area 0.8 to 3.8 ha) cooled by an average of 0.4 to 0.8°C over approximately 30 to 120 m

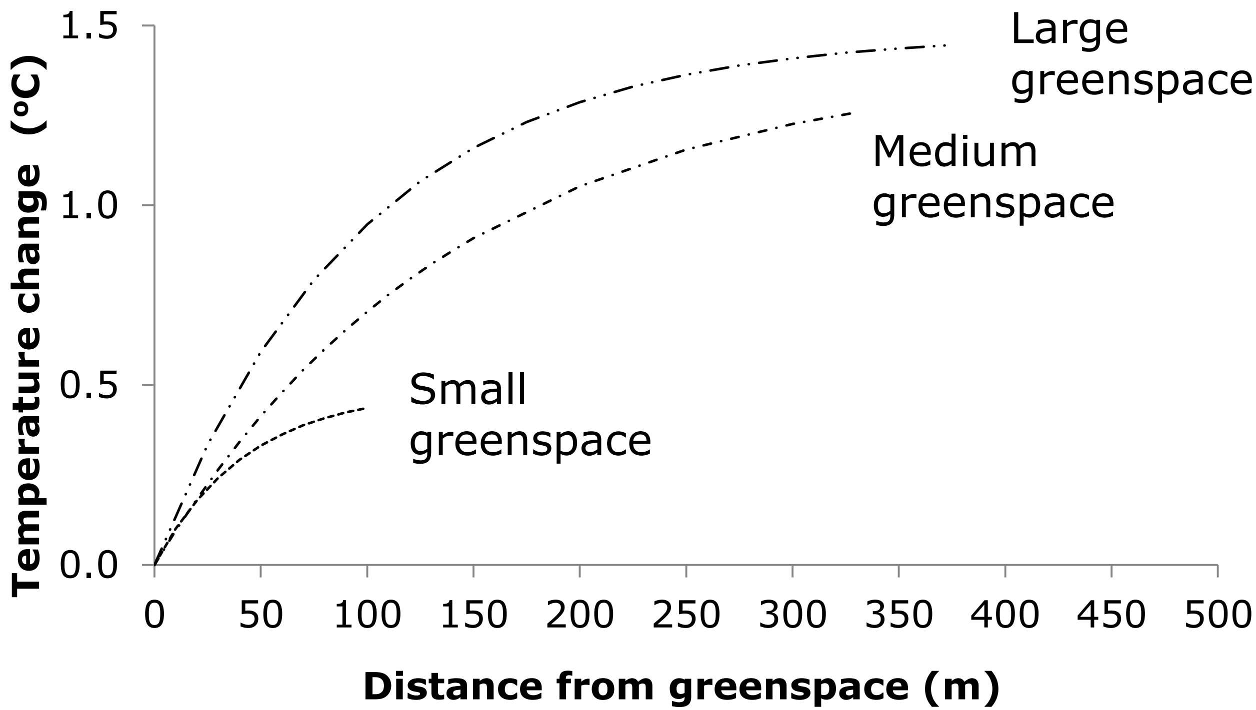
Medium greenspaces (area 10.1 to 12.1 ha) cooled by an average of 0.6 to 1.0°C over approximately 180 to 330 m

A. very small greenspace (Grosvenor Gardens, 27 June)
B. small greenspace (Russell Square, 20 September)
C. medium greenspace (Queen's Park, 18 August)

Results 2012



Cooling distance increased linearly with increasing area of greenspace but the relationship between area and the amount of cooling was non-linear



Greenspaces with area >0.5 ha can reduce the air temperatures of their surrounding areas during warm and calm nights

Amount of cooling provided increases with area of greenspace

Urban Heat Island abatement by greenspaces

A study into pan-London cooling

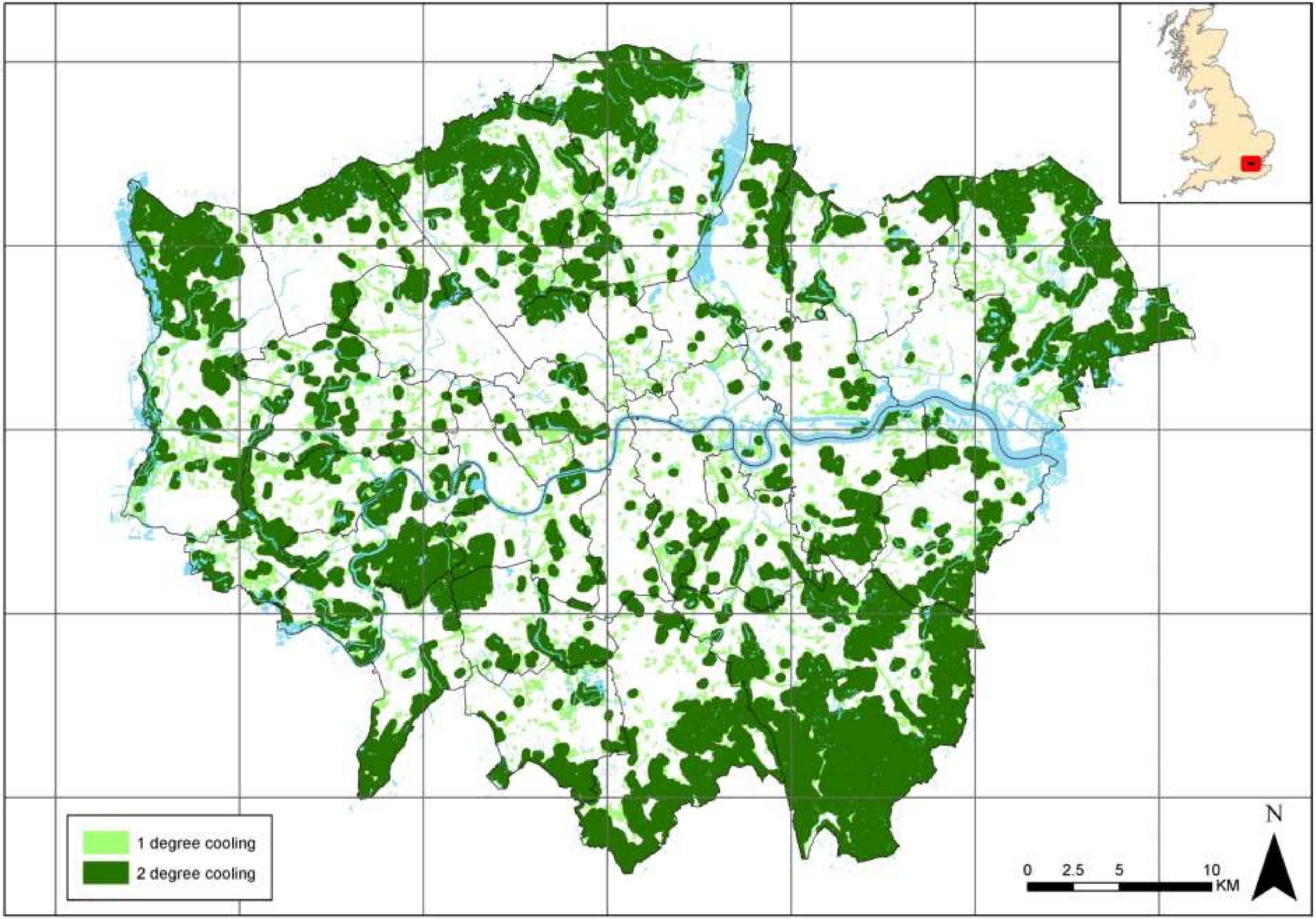
Cooling boundaries

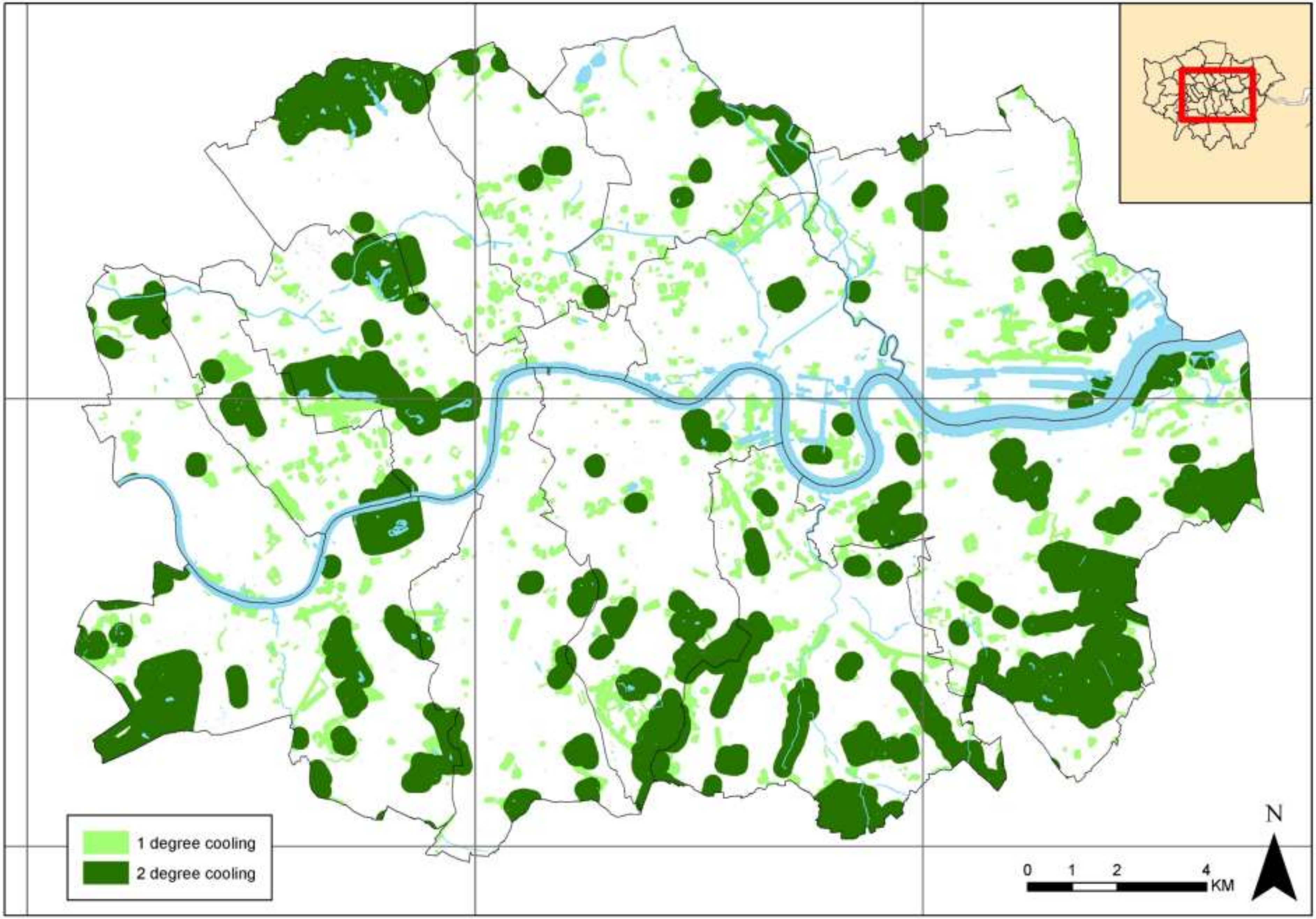
Size	Cooling Distance	Reference
Very small (≤ 0.5 ha)	10 - 20 m	1-2°C cooling for 20 m, 0.24 ha park in Kumamoto City, Japan (Saito et al. 1990) Cooling boundary approximates to greenspace width (Yu & Hien, 2006: mathematical model).
Small (0.5-1 ha)	50 – 150 m	1.5°C cooling for 150 m, 0.5 ha park in Haifa, Israel (Givoni 1998) 0.30°C cooling for 80 m around green sites of width 20 – 60 m) in Tel Aviv, Israel (Shashua-Bar and Hoffman 2000).
Medium (2- 100 ha)	200 – 1000 m	0.9°C cooling for 30 m, 3.6 ha park in Goteborg, Sweden (Upmanis et al. 1998). 1.5°C cooling for 1 km, 60 ha park in Tama New Town, Japan (Ca et al. 1998) 3°C cooling for 50 m around parks of up to 27 ha in Fukuoka City, Japan (Katayama et al. 1993)
Large (>100 ha)	400 – 2000 m	Chapultepec Park (500 ha) in Mexico City cooling distance ca. 2 km (Jauregui 1991). 4°C cooling over 775 m, 156 ha park in Goteborg, Sweden (Upmanis et al. 1998).

Cooling boundaries

FTC	Description	Type
1	Building	Artificial
2	Man-made surfaced area	Artificial
3	Vegetated/natural area – predominantly grass and low vegetation	Grass
4	Water	Blue space
5	Man-made structure other than building	Artificial
6	Vegetated/natural area – scattered trees (>30% and <70% cover)	Greenspace
7	Vegetated/natural area – predominantly trees (>70% cover)	Greenspace
8	Not used	
9	Non geographic entity type	

FTC = feature type code


1 degree cooling
2 degree cooling
0 2.5 5 10
KM
N


1 degree cooling
2 degree cooling
0 1 2 4
KM
N

Results (1)

London Borough	Area Cooled		Population		Age			Sex		Health		
Inner London	(Ha)	(%)	Total	Un-cooled	<4	5-74.	>75	Males	Females	Good	Fair	Not Good
City of London	13	4.0	7.4	6.5	0.2	6.7	0.4	4	3	6.5	0.6	0.2
Tower Hamlets	278	12.9	254	229	17.9	218	7.1	125	118	202	25.9	14.7
Hammersmith and Fulham	247	14.4	182	175	11.1	153	6.8	83	88	146	16.1	8.3
Lambeth	395	14.5	303	278	19.2	252	9.8	140	141	239	28.9	13.2
Hackney	337	17.7	246	227	17.8	204	7.2	114	116	190	25.0	14.2
Islington	268	18.0	206	176	11.2	169	7.4	93	96	155	21.1	12.1
Newham	741	19.2	308	272	22.5	242	8.1	142	131	227	30.9	15.4
Kensington and Chelsea	301	24.3	159	134	8.3	128	7.4	71	73	124	13.1	6.5
Camden	535	24.5	220	205	12.0	179	10.1	99	103	169	21.0	11.3
Southwark	761	25.4	288	253	18.3	226	9.1	126	128	215	26.4	12.5
City of Westminster	743	33.7	219	189	10.5	162	9.4	93	89	153	18.3	10.6
Lewisham	1,237	35.0	276	206	17.2	189	9.8	106	110	179	25.3	11.2
Wandsworth	1,261	35.8	307	248	17.6	221	10.1	121	128	217	22.1	9.4
Greenwich	1,934	38.3	255	192	16.1	170	9.6	97	99	163	22.6	10.5
Totals	***9,050***	***26.0***	***3,232***	***2,790***	***200***	***2,522***	***112.3***	***1,411***	***1,423***	***2,387***	***297***	***150***

Population figures are ‘thousands’. ‘Cooled’ populations refers to those people living within an area cooled by a 2^{o}C cooling boundary and or multiple cooling boundaries

Results (2)

Scenario		CI 5%	No. deaths	CI 95%
Modelled	With current cooling	107	145	184
	Assume: no cooling	124	168	212
	1°C Cooling pan-London	62	83	106
	2°C Cooling pa-London	26	35	44
Present	Lives saved with current cooling	17 (124-107=)	23 (168-145=)	29
	Value (£)	£29.1 million	£39.3 million	£49.8 million
	Lives saved with 2°C cooling across London	98	133	168
	Value (£)	£171 million	£232 million	£294 million

No. of deaths in a heatwave values from Hajat et al. (2002)

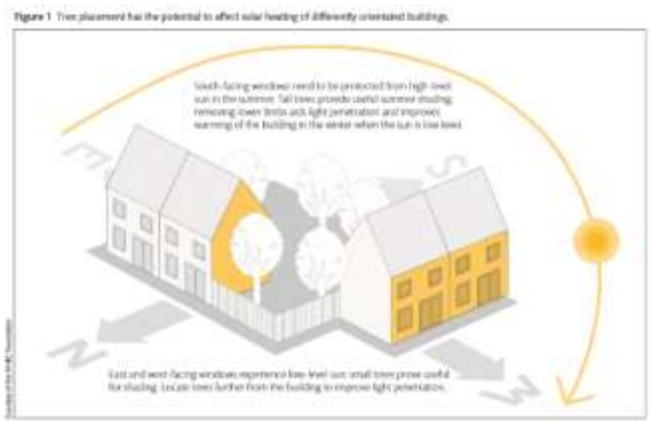
Urban Heat Island abatement by greenspaces

'Research Notes 12 And 37'

RN12 "Air temperature regulation by urban trees and green infrastructure" published in Feb 2013

- *Draws together scientific evidence to outline the:*
  - *causes of urban heat islands*
  - *role of trees and wider green infrastructure in combating UHI*
  - *effects of urban heat islands on human health*

- *Impact of vegetation (mechanisms of cooling)*
- *Spatial scales of cooling*
- *The right tree in the right place*
  - *Tree selection*
  - *Tree location*
- *Other adaptations to mitigate UHI*
- *Potential conflicts*



RN37 "The role of urban trees & green spaces in mitigating urban heat islands" published in Jan

Figure 4. Current knowledge of design strategies that can lead to maximum greenspace and tree cooling.

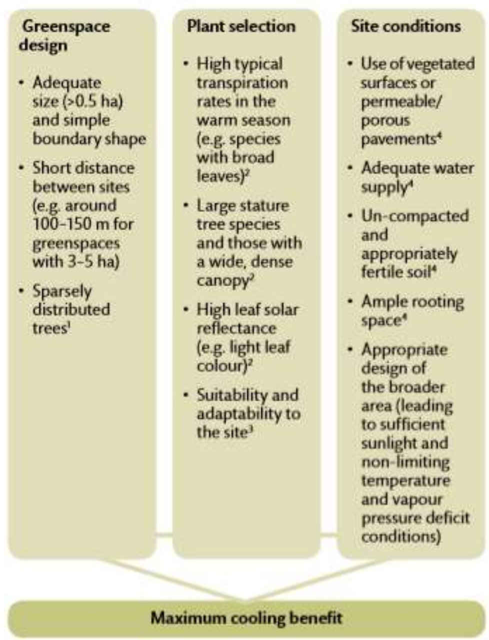
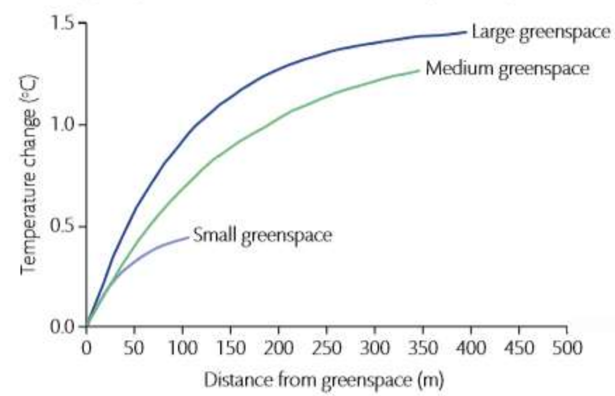
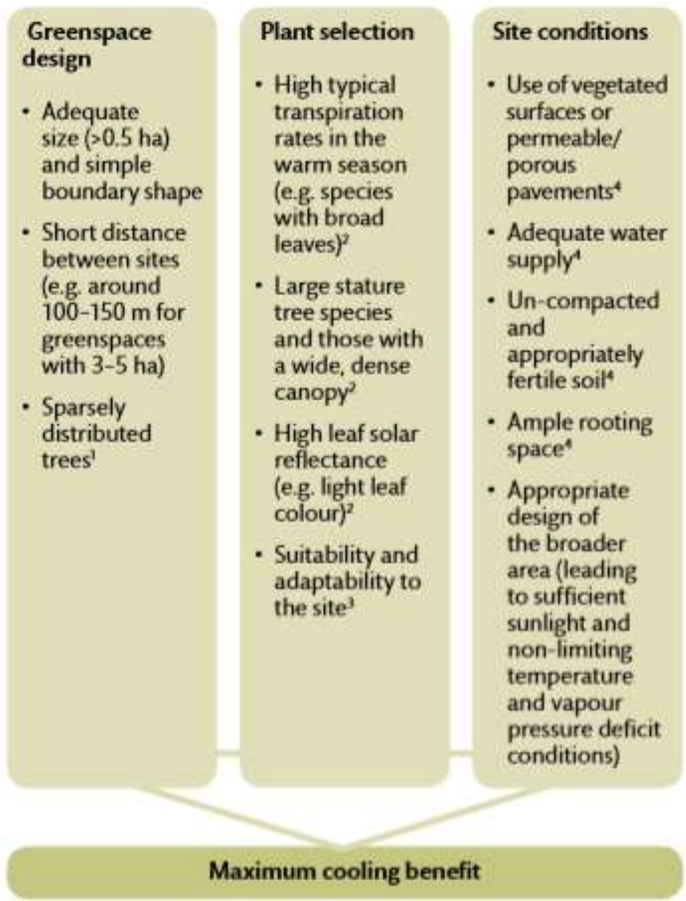


Figure 2. An example of estimated air temperature increase with increasing distance from greenspaces of different sizes (small: 2.5 ha; medium: 12 ha; large: 111 ha) during selected warm and calm nights up to a distance where the air temperature plateaued.



RN37

Figure 4. Current knowledge of design strategies that can lead to maximum greenspace and tree cooling.



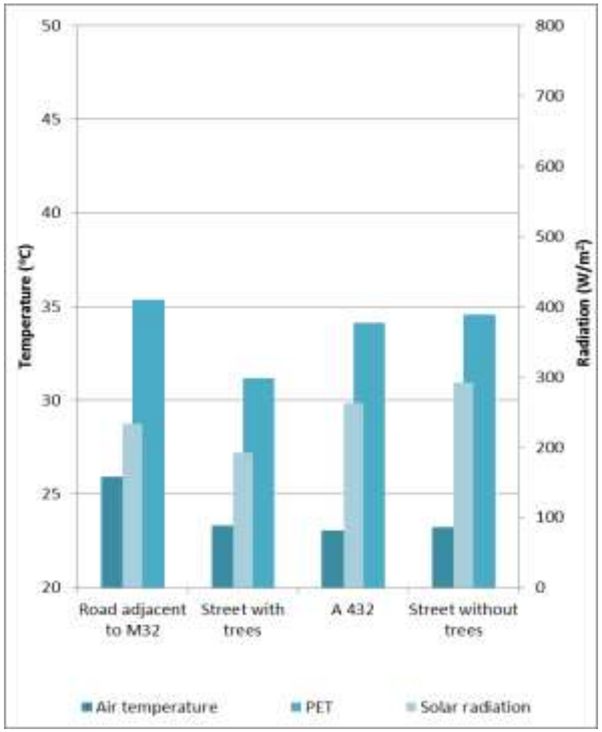
- *Cooling across the entirety of an urban area requires greenspaces to be closely spaced*
- *Greenspaces should be treed, but care is required in the placement of trees*
- *Some trees are better at cooling*
  - *shape and size*
  - *transpiration rates*
  - *reflectivity*
  - *larger canopies*

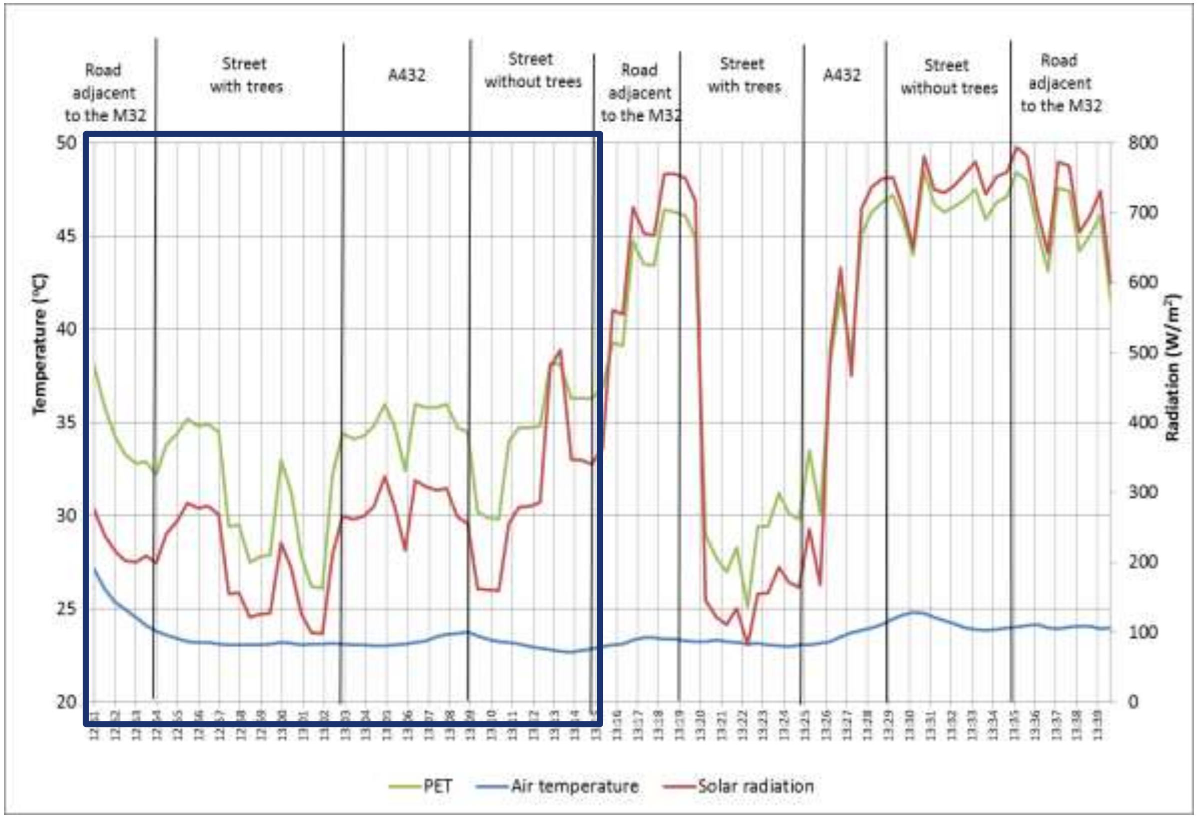
  (provided they are healthy and have enough space, soil water and nutrient resources to maintain their growth)
- *The tree's aerial and soil environment is as important as the tree itself*

Cooling by street trees

The role of street trees in improving thermal comfort in Bristol

- Two streets have been selected for a pilot study: Freemantle road (220 m long, 20 m wide) with mature street trees and Glen Park (150 m long, 15 m wide) with no street trees.
- Mobile weather station measuring incoming solar radiation, air temperature and humidity at 2 m height.


50
45
40
35
30
25
20
800
700
600
500
400
300
200
100
0
Temperature (°C)
Radiation (W/m²)
Road adjacent to M32
Street with trees
A 432
Street without trees
Air temperature
PET
Solar radiation

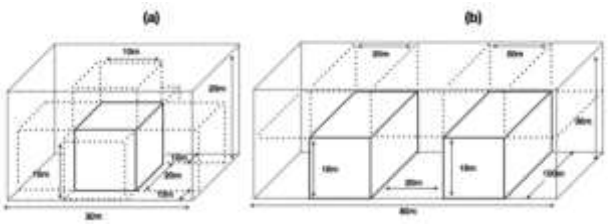

Road adjacent to the M32
Street with trees
A432
Street without trees
Road adjacent to the M32
Street with trees
A432
Street without trees
Road adjacent to the M32
50
45
40
35
30
25
20
800
700
600
500
400
300
200
100
0
Temperature (°C)
Radiation (W/m²)
PET
Air temperature
Solar radiation

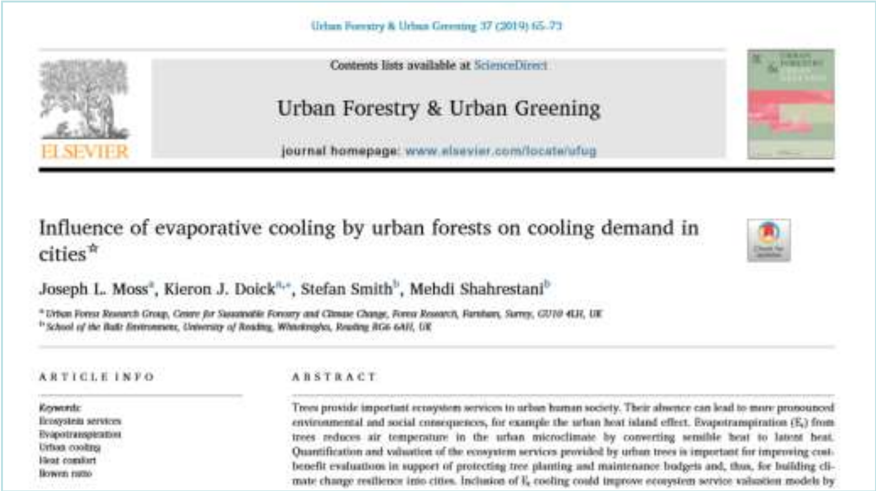
Valuing cooling

Valuing cooling by urban forests

- Climate regulation is one of many ‘ecosystem services’ provided by the urban forest
- Value it? (like for carbon sequestration, and air pollution removal)
- i-Tree Eco estimated urban forest composition
- Quantified estimation of evapotranspiration
- TRNSYS and TRNFLOW modelling

(dynamic building thermal and airflow modelling programs)





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ELSEVIER

Influence of evaporative cooling by urban forests on cooling demand in cities☆

Joseph L. Moss[a], Kieron J. Doick[a,*], Stefan Smith[b], Mehdi Shahrestani[b]

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ARTICLE INFO

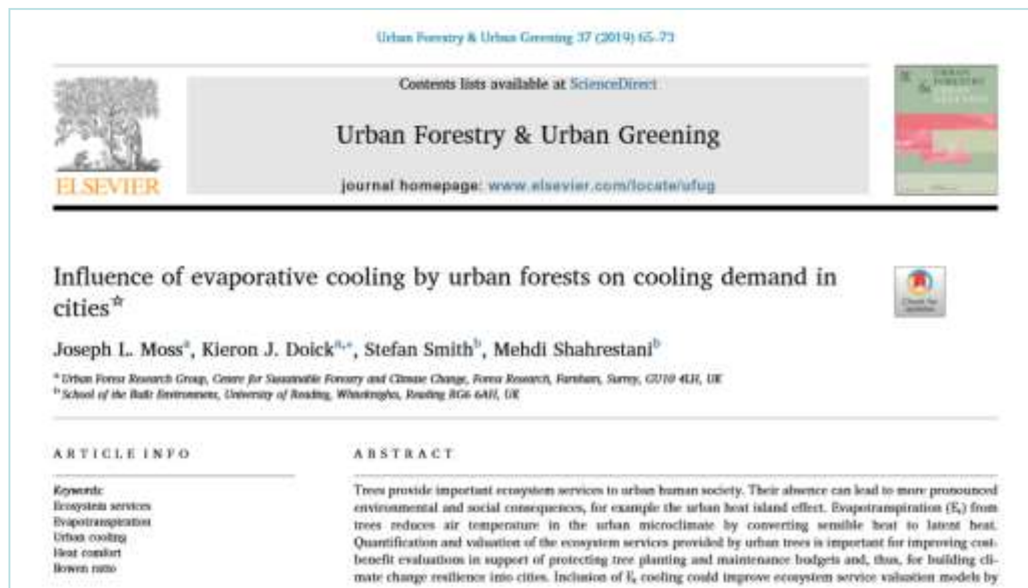
Keywords:
Ecosystem services
Evapotranspiration
Urban cooling
Heat comfort
Bowen ratio

ABSTRACT

Trees provide important ecosystem services to urban human society. Their absence can lead to more pronounced environmental and social consequences, for example the urban heat island effect. Evapotranspiration (E_t) from trees reduces air temperature in the urban microclimate by converting sensible heat to latent heat. Quantification and valuation of the ecosystem services provided by urban trees is important for improving cost-benefit evaluations in support of protecting tree planting and maintenance budgets and, thus, for building climate change resilience into cities. Inclusion of E_t cooling could improve ecosystem service valuation models by

Valuing cooling by urban forests

- Energy savings to air-conditioned of buildings
- Trees shown to provide substantial cooling
- A modelled 1.3 –13.4% reduction in air-conditioning unit energy consumption
- Equivalent to £2.1m to £22m in electricity costs
- Key species:
    - Castanea sativa
    - Prunus avium
    - Quercus petraea
    - Platanus hybrida
    - Fagus sylvatica



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Bowen ratio

ABSTRACT

Trees provide important ecosystem services to urban human society. Their absence can lead to more pronounced environmental and social consequences, for example the urban heat island effect. Evapotranspiration (E_t) from trees reduces air temperature in the urban microclimate by converting sensible heat to latent heat. Quantification and valuation of the ecosystem services provided by urban trees is important for improving cost-benefit evaluations in support of protecting tree planting and maintenance budgets and, thus, for building climate change resilience into cities. Inclusion of E_t cooling could improve ecosystem service valuation models by

Species selection for cooling

How do you select trees for cooling?

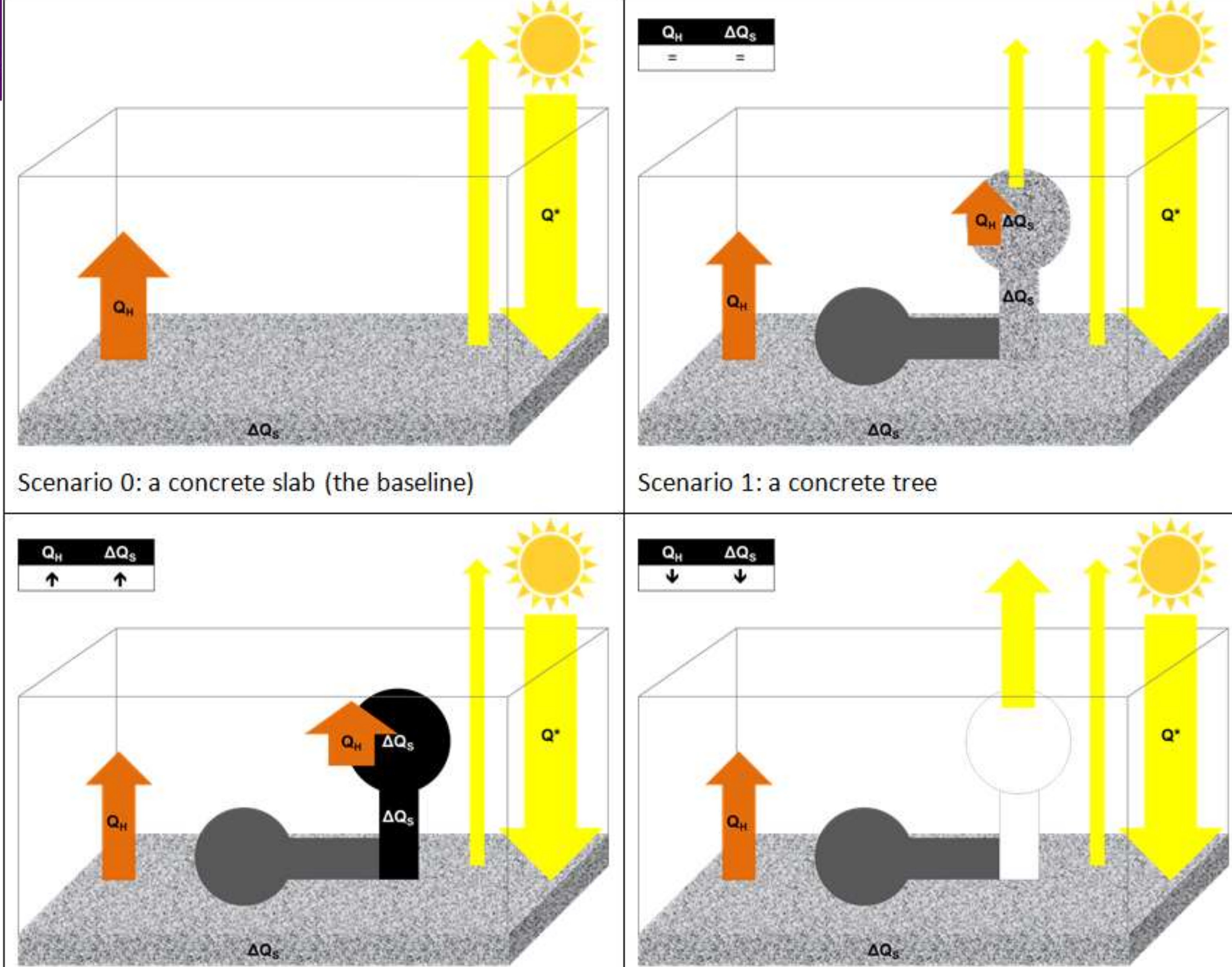
The solution
Three equations are proposed that allow comparison of the relative abilities of trees to cool

Transpiration = crown diameter * LAI [a] * canopy aspect ratio * stomatal conductance [b]

Reflection = albedo * crown diameter * LAI

$$\textit{Shading} = \frac{\textit{crown diameter} * \textit{LAI} * \textit{tree height}}{\textit{canopy aspect ratio}}$$

*Where: [a] LAI = leaf area index; [b] stomatal conductance (**or:** growth rate)*

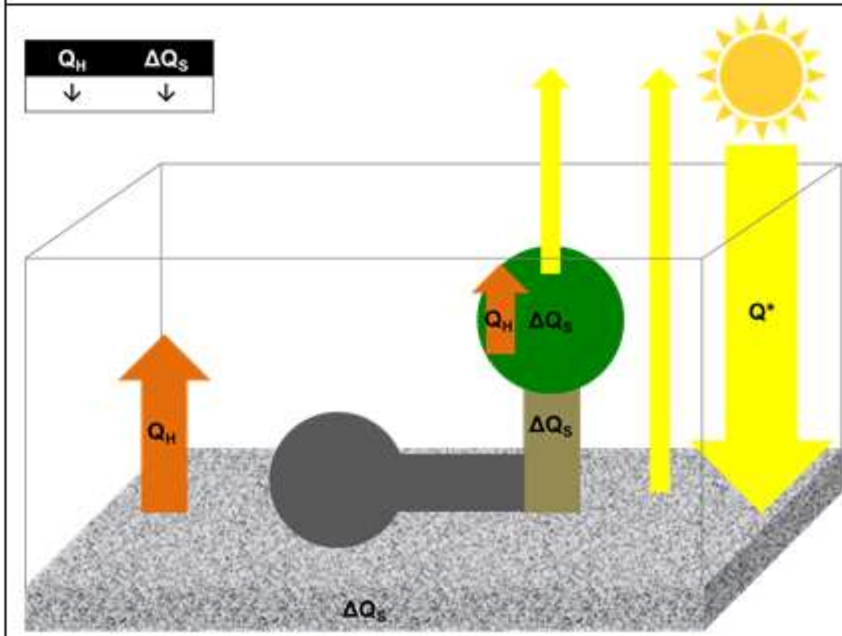


Scenario 0: a concrete slab (the baseline)

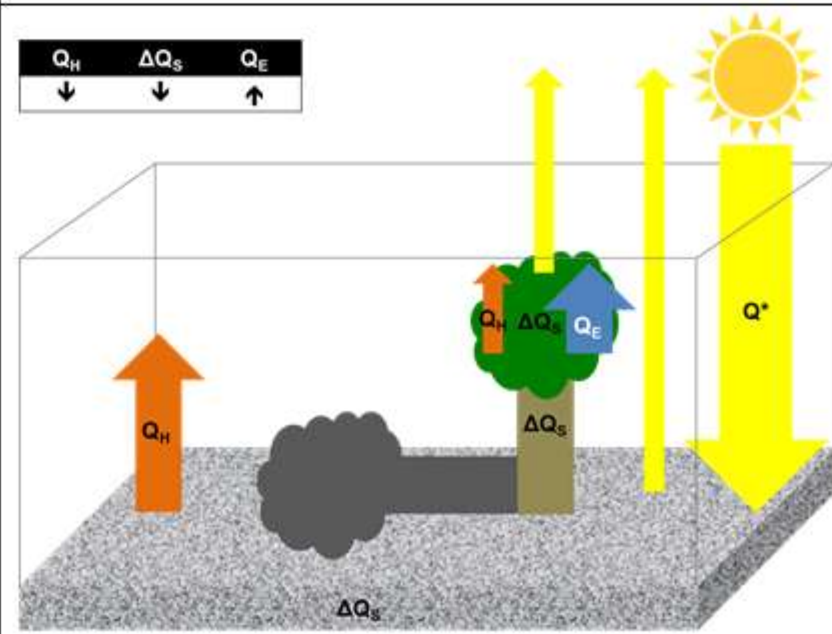
Scenario 1: a concrete tree

Scenario 2: a concrete tree painted black

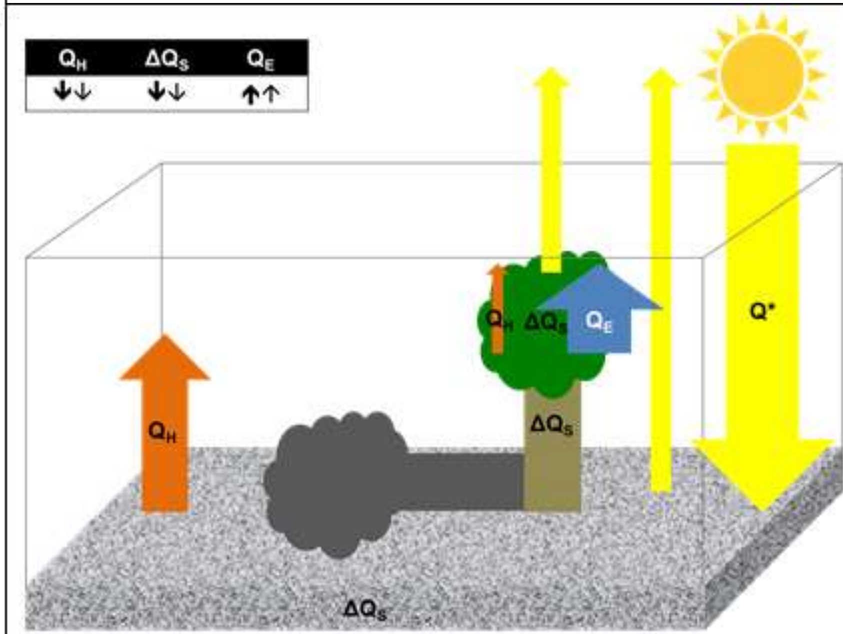
Scenario 3: a concrete tree with reflective paint



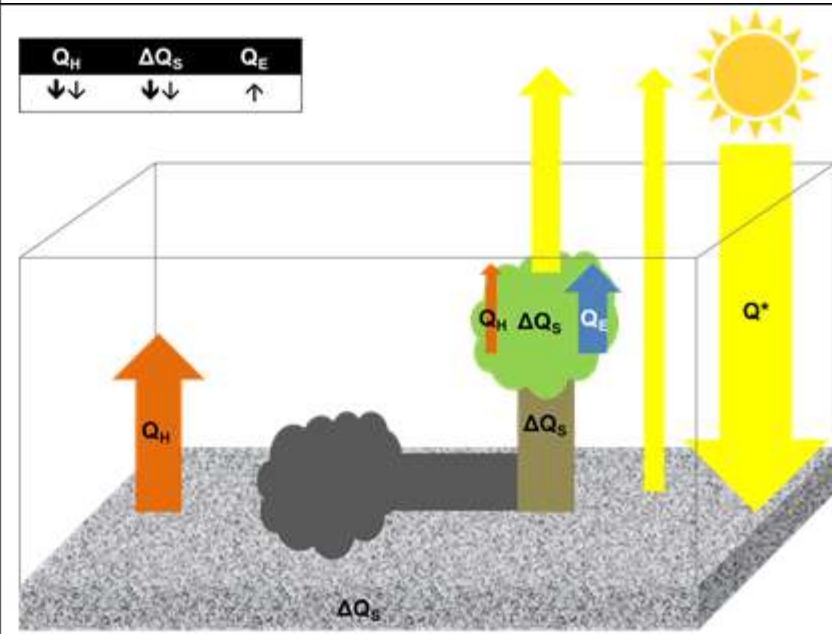
Scenario 4: a tree that does not transpire



Scenario 5: a real tree (a baseline tree)



Scenario 6: a faster-growing species



Scenario 7: a species with a higher albedo

How to use the equations

- Start with a short list of species/cultivars suited to the location (remembering scenarios 10-14)
- Apply actual, estimated or relative values to each parameter in Equations 4 to 6 for each of short-listed options
- (assume) that the tree species that scores highest in relation to all three cooling mechanisms will be more effective at providing urban cooling.
- Consider need/desire to balance other benefits, e.g. contribution to sense of place, biodiversity

Table 2: Rating of the 32 tree species/cultivars for the cooling mechanisms: transpiration, reflection, and shading, and their overall impact classification.

Latin name	Transpiration	Reflection	Shading	Overall impact
Acer campestre				
Acer platanoides				
Acer pseudoplatanus				
Aesculus hippocastanum				
Alnus spp.				
Betula pendula				
Carpinus spp.				
Cedrus spp.				
Chamaecyparis lawsoniana				
Crataegus monogyna				
Eucalyptus spp.				
Fagus sylvatica				
Fraxinus excelsior				
Ilex spp.				
Laburnum spp.				
Laurus nobilis				

Forest Research

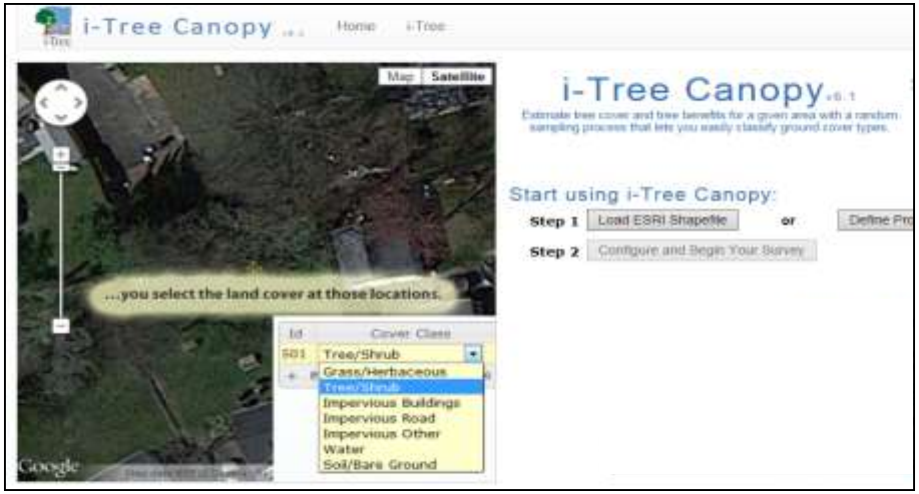
i-Tree Canopy:

can you help us build an Urban Canopy Cover map for the UK?

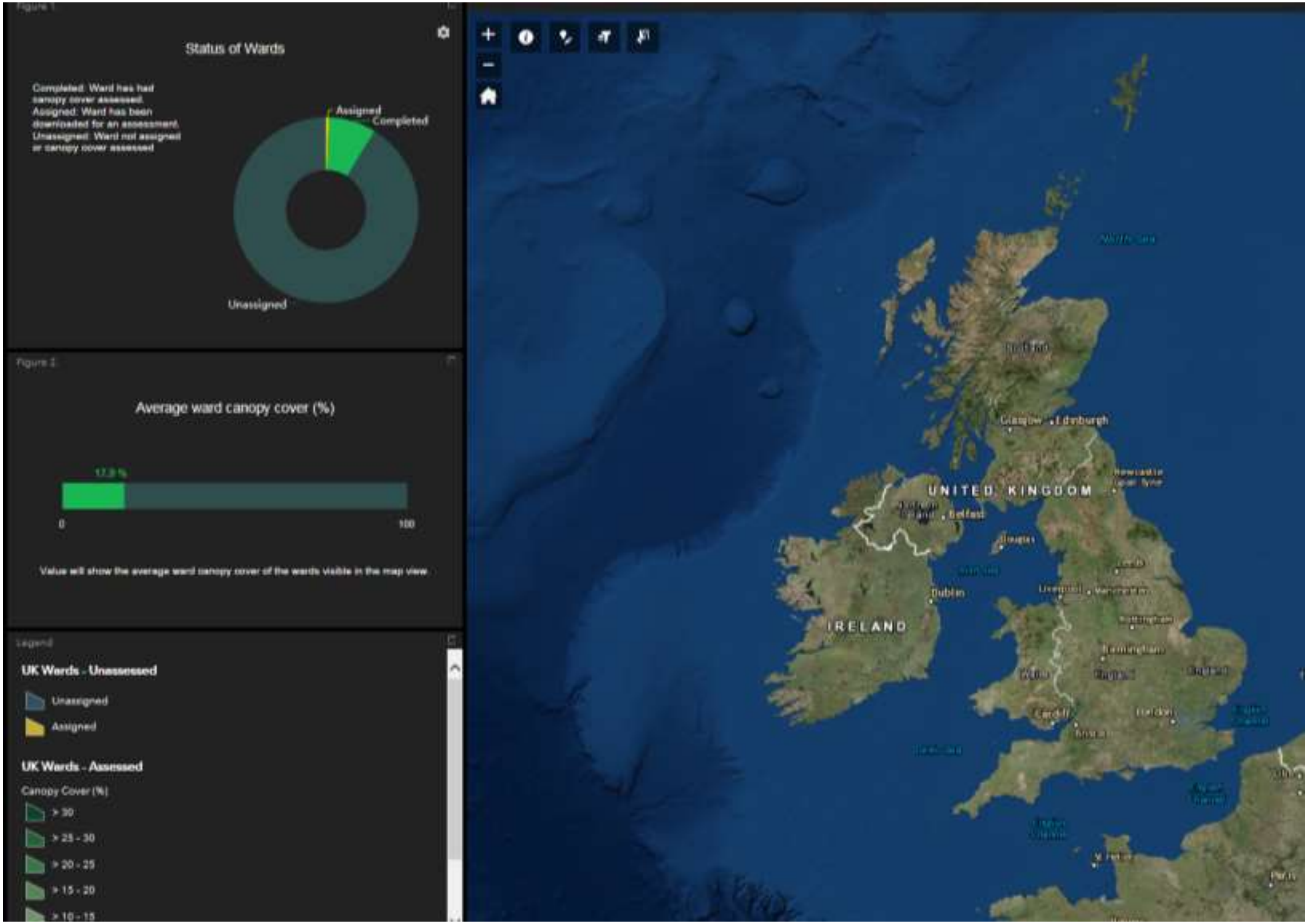
What it looks like to get involved….

visit
https://www.forestresearch.gov.uk/research/i-tree-eco/urbancanopycover/

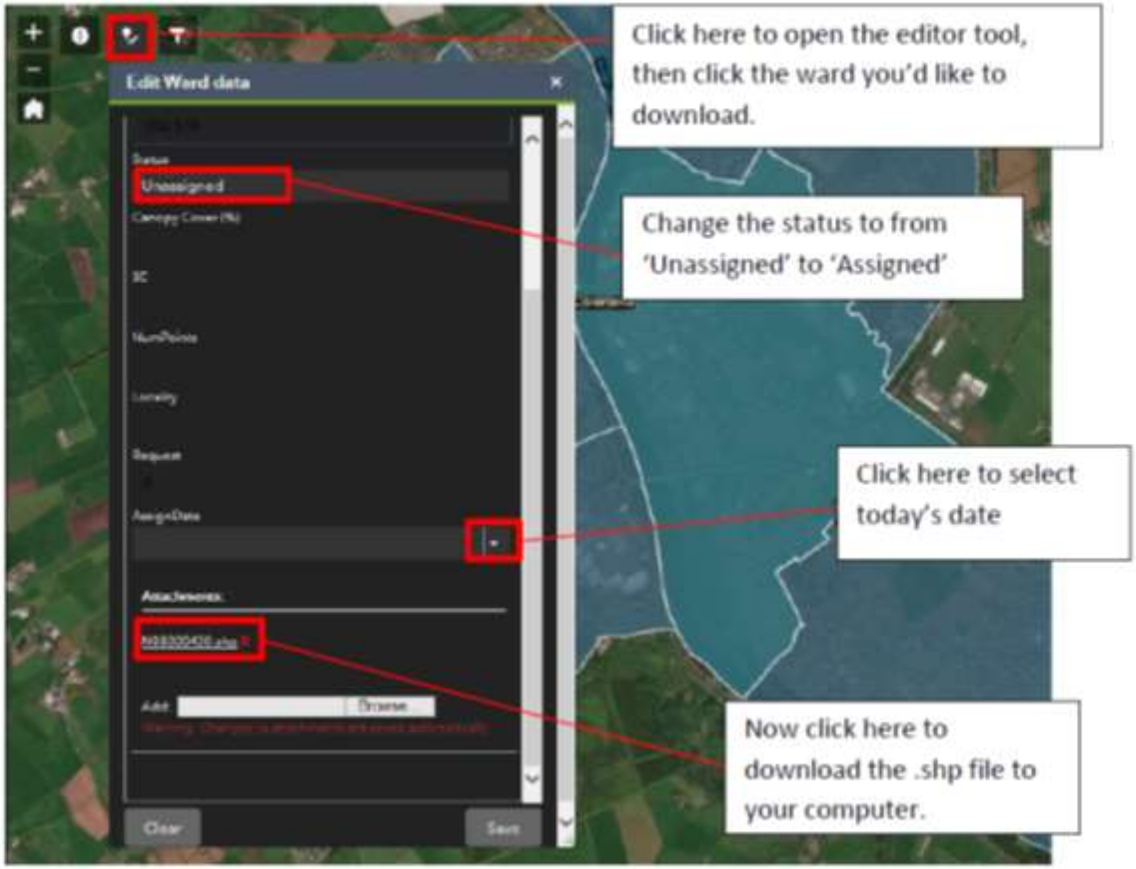
for our step-by-step guide and to learn about the project aims and objectives



The 'Map' and 'Results' pag



Step-by-step, the guid

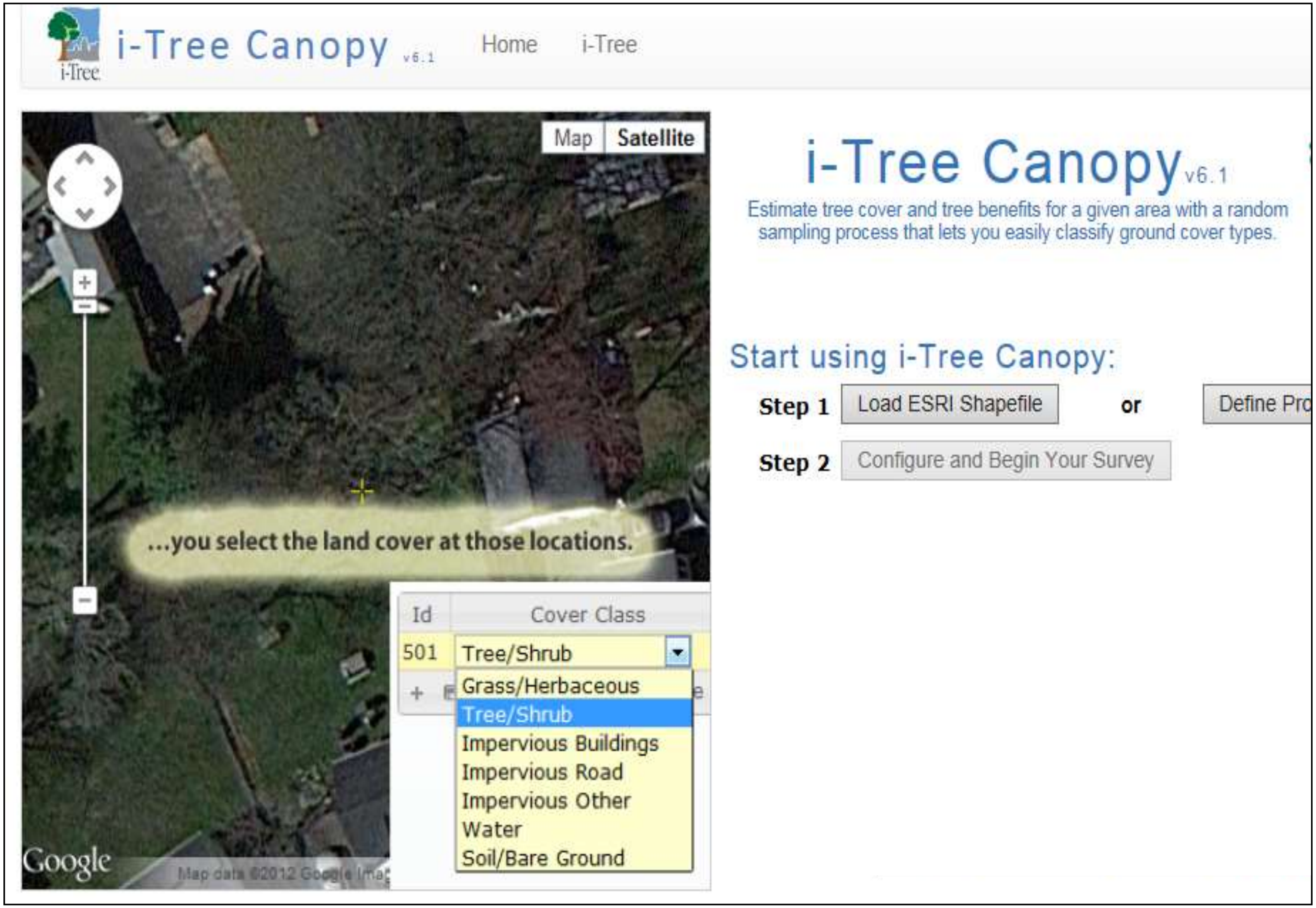


iii) Go to https://canopy. itreetools.org/ and click the button 'load ESRI Shapefile'. Upload the .shp file you have just downloaded.

iv) Once uploaded the page will refresh and you should now see your boundary outlined in red on a Google map, to the left-hand side of the screen. **Proceed to Step 2**.

B. Contact us to get the official ward boundaries. We'll email you a file (an ESRI GIS shape-file)

i-Tree Canop


i-Tree
i-Tree Canopy v6.1
Home
i-Tree
Map
Satellite
...you select the land cover at those locations.
Id
Cover Class
501
Tree/Shrub
Grass/Herbaceous
Tree/Shrub
Impervious Buildings
Impervious Road
Impervious Other
Water
Soil/Bare Ground
Google
i-Tree Canopy v6.1
Estimate tree cover and tree benefits for a given area with a random sampling process that lets you easily classify ground cover types.
Start using i-Tree Canopy:
Step 1
Load ESRI Shapefile
or
Step 2
Configure and Begin Your Survey

What does it look like.

Trees & Design Action Group

Result

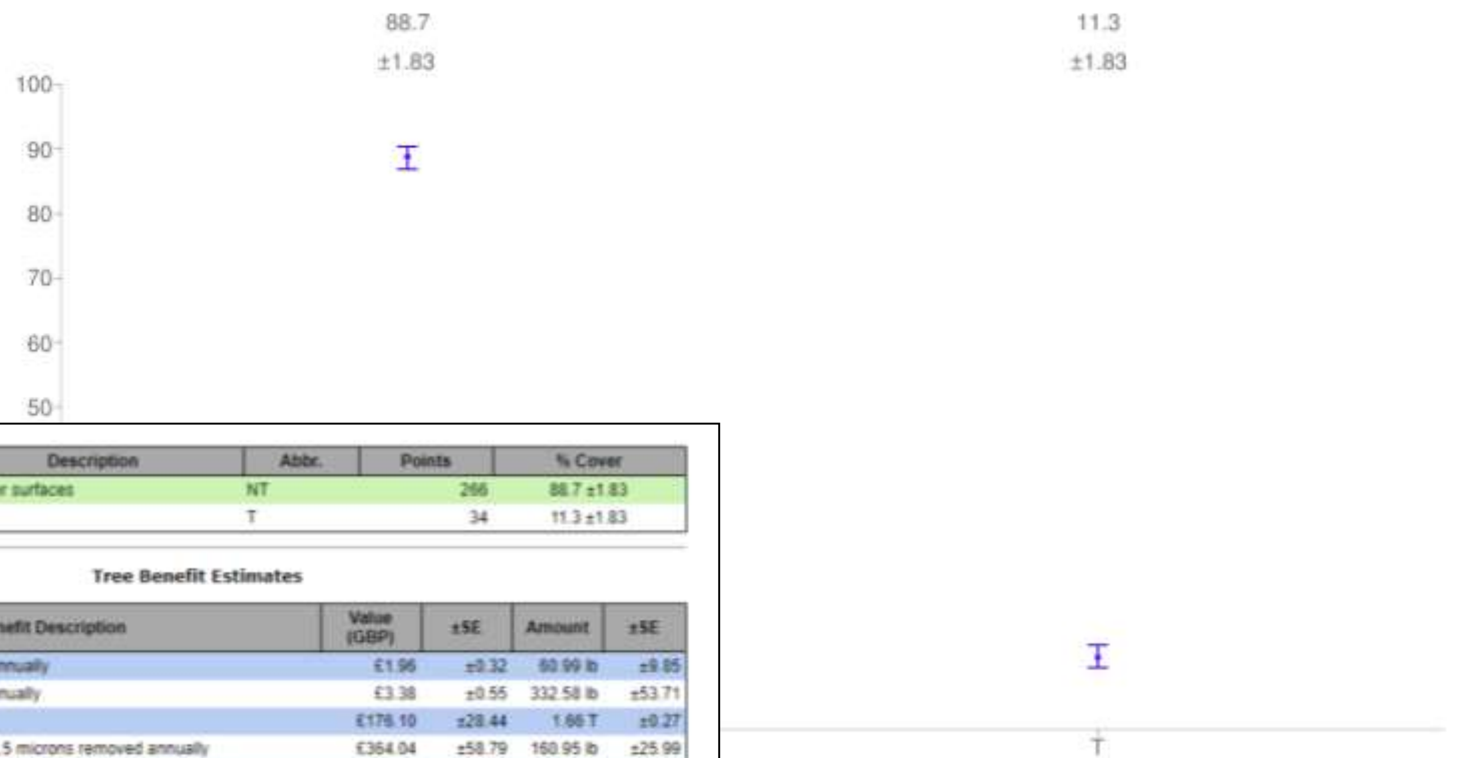
Trees & Design Action Group

i-Tree Canopy v6.1

Cover Assessment and Tree Benefits Report

Estimated using random sampling statistics on 10/10/18

Percent Cover (±SE)



Cover Class	Description	Abbr.	Points	% Cover
Non-Tree	All other surfaces	NT	266	88.7 ±1.83
Tree		T	34	11.3 ±1.83

Tree Benefit Estimates

Abbr.	Benefit Description	Value (GBP)	±SE	Amount	±SE
CO	Carbon Monoxide removed annually	£1.96	±0.32	60.99 lb	±9.85
NO2	Nitrogen Dioxide removed annually	£3.38	±0.55	332.58 lb	±53.71
O3	Ozone removed annually	£176.10	±28.44	1.66 T	±0.27
PM2.5	Particulate Matter less than 2.5 microns removed annually	£364.04	±58.79	160.95 lb	±25.99
SO2	Sulfur Dioxide removed annually	£0.59	±0.10	209.58 lb	±33.85
PM10*	Particulate Matter greater than 2.5 microns and less than 10 microns removed annually	£127.85	±20.65	1,109.51 lb	±179.17
CO2seq	Carbon Dioxide sequestered annually in trees	£9,031.81	±1,458.53	337.22 T	±54.46
CO2stor	Carbon Dioxide stored in trees (Note: this benefit is not an annual rate)	£227,720.08	±36,774.10	8,502.45 T	±1,373.05

The end…

My thanks to…

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