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The canopy cover Webmap of the United Kingdom's towns and cities

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ABSTRACT

Urban trees and other green infrastructure are advocated as a cost-effective sustainable solution to ameliorate the socio-economic and environmental challenges of urbanisation. UK research has only recently started to quantify urban trees. Tree canopy cover percentage (TCC) is a useful indicator of tree presence. Its estimation can be reproducible, simple, fast, and cost-effective; it can also be evaluated through citizen science, improving people's appreciation for urban trees and widening the data collection resource pool. This research summarises a citizen science assessment of the TCC of the UK's 5,749 urban wards. Descriptive statistics are presented spanning local authority to country. The area-weighted mean (and standard error) of TCC across urban wards was 17.3 ± 0.1%. Nationally, the TCC were 11.8 ± 0.5%, 15.7 ± 0.5%, 17.5 ± 0.2%, and 18.1 ± 0.5%, for Northern Ireland, Scotland, England, and Wales, respectively. Results show that only 27.6% of urban wards had a TCC higher than 20%, previously suggested as a minimum target for UK towns. The findings highlight substantial geographical variance in TCC equity, as well as a negative correlation between TCC and deprivation. This information will be of value in urban forest strategy and management.

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Urban tree canopy cover; i-Tree canopy; citizen science; Urban forest management; electoral ward

Introduction

The estimated global population has risen by seven billion since the nineteenth century (Rosner et al., 2019), and the proportion of people who are urban-dwelling rose by twenty-seven-fold (United Nations Digital Library UNDL, 2018; Zhang, 2016). Likewise, the UK population has expanded, increasing from 50 million when records began in 1950 to a current 67 million. It is projected to rise to 72 million by 2041 (ONS, 2021a). England's urban populace has been growing faster than its rural one, and now accounts for 83% of UK total population (Government Office for Science GOS, 2021).

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Increasing population and urbanisation bring both benefits and challenges (Zhang, 2016). The urban forest, comprising all the trees in the urban realm, in public and private spaces, along linear routes and waterways and in amenity areas (Davies et al., 2017), can help mitigate some of the challenges of urbanisation in a cost-effective and sustainable way as they provide a range of benefits (also called ecosystem services – ES) to society (Konijnendijk, 2022). For example, urban forests decrease air-borne pollutants (Nowak et al., 1998), reduce stormwater risk (Booth et al., 2002), mitigate temperatures during extreme events (Deilami et al., 2018), support biodiversity, and improve human health and wellbeing (Nghiem et al., 2021).

The size and health of canopies are important proxies for ES quantification of trees and are commonly used in methodologies like i-Tree Eco (Hirabayashi, 2013; Nowak et al., 1998). Tree canopy cover percentage (TCC) is a land-cover class and a two-dimensional metric indicating the area of leaves, branches, and stems of trees viewed from above across a given area, regardless of what other land-cover classes may lie underneath. It is an easily accessible measure that can be used to estimate some ES directly or through other related measures such as leaf area index (a plant-based metric defined as the leaf surface area per unit area of ground) (Doick et al., 2017).

Quantifying TCC is an important first step in the management of the urban forest (Schwab, 2009). However, it is not widely available at fine spatial scale, such as electoral ward, in the UK. This paucity of urban TCC data has so far limited the ability to set: i) realistic and timely percentage increase targets, ii) target planting locations so ES provision is available where needed the most, and iii) a baseline for subsequent monitoring. Realistic and efficient TCC goals that consider constraints and conflicting demands are especially important to maximise urban forest benefit. In addition, TCC baselining as fine-scale seems urgent, as canopy cover appears to be decreasing over past decades (Doick et al., 2020; Urban Forest and Woodland Advisory Committee Network UFWACN, 2016; World Resources Institute WRI, 2022).

Independent urban TCC studies exist at local scales, for example, Kent County Council's Environment Strategy (Kent County Council KCC, 2020), the Greater London Authority's Curio canopy map (Greater London Authority GLA, 2023), the Bristol Tree Forum (Bristol Tree Forum, 2022), Natural Resource Wales (NRW)'s Town Tree Cover reports (NRW, 2016), as well as discrete Treeconomics and Forest Research (FR) reports, including for Oxford, Wycombe, Reading, Newcastle, Plymouth, Cambridge, and various London boroughs (Treeconomics, 2023; Urban Forest Research Group UFoRG, 2023). These are, however, hard to compare due to the mix of methodologies employed. To start addressing the lack of comparable nationwide data, a Forestry Commission TCC quantification study was conducted for 283 English towns and cities (Doick et al., 2017). Its primary aims were to begin baselining TCC and to evaluate the performance of different estimation methods. However, the other countries of the UK were only sparingly considered.

Recently, datasets such as the National Tree Map (BlueSky, 2023), the Friends of the Earth and Terra Sulis tree canopy map, and the National Forest Inventory's Trees Outside Woodlands (NFI-TOW) (Forest Research, 2022) have been released from which urban forests metrics can be derived. However, there are limitations. Some have restricted access (National Tree Map and NFI-TOW), some have not published validations (NFI-TOW and Terra Sulis tree canopy map), and some do not include all trees (NFI-TOW). Other

urban forest quantification projects exist for the UK, e.g. Treezilla (The Open University, FR, & Treeconomics, 2023) and Global Forest Change (WRI, 2022), but these are still progressing.

For this reason, Forest Research, with partners Brillianto, Trees for Cities, and Woodland Trust, ran a project aiming to complete a TCC Webmap of the UK's 5749 urban wards. All urban wards have now been surveyed by citizen scientists using the i-Tree Canopy tool (https://canopy.itreetools.org/; part of the i-Tree suite developed by the USA i-Tree Cooperative – an initiative involving the USDA Forest Service, Davey, Arbor Day Foundation, the Society of Municipal Arborists, International Society of Arboriculture, and Casey Trees).

This Webmap has the advantages over other datasets of being open source, complete (for urban wards), and collected at a relatable common granular spatial scale: electoral ward. It is also a multi-organisational citizen science project; such projects have proven to have a dual benefit of raising the awareness of tree benefits and thus facilitating management of urban forests and utilising sample sizes unlikely to be achieved without the voluntary contributors (Chapman et al., 2017).

This paper presents the initial summary of the TCC Webmap dataset and highlights initial patterns in TCC across various spatial scales. Several UK tree planting funds exist (Forestry Commission, 2023; The Queen's Green Canopy, 2023; Trees for Cities, 2023); the Webmap is likely to be a useful resource for urban foresters to improve the management of urban trees – including the targeting of tree planting – and inform local authorities on how to meet future planting objectives efficiently and equitably.

Materials and methods

Sampling strategy, study area, and urban definition

The UK TCC Webmap (UFoRG, 2023), was set up in 2018 by FR, with partners Brillianto and Trees for Cities. In 2022, the Woodland Trust (WT) joined as an additional partner. The map consists of a WSG84 OS MasterMap base layer, a polygon layer of electoral wards defined from 2017 to 2018 boundaries (ONS, 2019b), and a satellite image layer (Earthstar Geographics, Esri, HERE, Garmin). The study area covered the whole of the UK, consisting of 9113 electoral wards. This paper focuses on the 63% ($n = 5{,}748$) which are "urban" and excludes the "rural" subset. As of December 2022, TCC data have been collected for 100% of urban, and 56% of rural, wards. In the UK, urban areas are predominately defined in two ways: by population density or by population size of a physical settlement (Bibby & Brindley, 2013; Office for National Statistics ONS, 2016). Here, wards smaller than 1000 hectares were classified as urban. Electoral ward unique identifiers were linked to higher geographies of LAs (ONS, 2019b), and regions and countries (ONS, 2019a).

From conception, the project aimed to incorporate citizen science. Therefore, the Webmap was designed for easy and meaningful communication to the citizen science volunteers of the objectives, and ready access to ward boundaries. Use of an online map provided simple visualisation of the TCC data and project progression.

Data collection with i-Tree canopy

Urban ward canopy cover samples were collected by over 400 volunteers between 2018 and 2022. Data collection was pseudo-randomised, with contributions primarily being elective choices. A sample of submissions from each contributor was quality assured for the accuracy of their canopy identification.

Collection used the open source and simple i-Tree Canopy tool (https://canopy.itreetools.org/). i-Tree Canopy randomly generates points within a defined polygon study area on a Google Maps satellite image. The user examines each point in sequence and records whether its centre falls on a tree canopy (tree) or elsewhere (non-tree). Satellite images vary in resolution, season, and presence and extent of shadows. Users differ in their definition of tree and shrub. Therefore, guidance was provided to standardise canopy identification, which was fully detailed and tested in Doick et al. (2017). The guidance recommended 300 data points per ward and for users to continue assessing additional points until the standard error (SE) was less than 2%. The average sampling effort was 418 points ± 144 (1SD) ($N = 5{,}749$ urban wards). The point data for most wards were saved and collated.

Data analysis

Data were analysed using the RStudio2022.07.2 + 576 wrapper (The RStudio Team, 2016) in R.4.2.1 (The R Core Team, 2022). Plots were created using "ggplot{ggplot2}" (Wickham & Chang, 2022). Visualisations combined violin plots, jittered raw data points, and measures of central tendency (CT, i.e. median, the arithmetic mean, and the mean weighted by study areas). Unless stated otherwise, means are area-weighted ± standard error. In violin plots, the width of the kernel is proportional to the density of data points; they have the advantage of highlighting multimodality. Descriptive statistics were calculated using custom functions based on "describeby{psych}" (Revelle, 2016). All statistics are rounded to one decimal place, besides p values, which are rounded to three.

Potential differences in TCC CT between geographic areas were analysed using generalised linear models (GLMs) in "glm{stats}" (The R Core Team, 2022a), fitted with logit-linked quasibinomial error distributions, as data were overdispersed (Thomas et al., 2015). After testing for a general statistically significant difference through log-likelihood ratio tests with "drop1{stats}", Tukey-alpha-adjusted pairwise multiple comparisons between geographic areas were calculated using "emmeans{lsmeans}" (Lenth et al., 2022). Potential differences in TCC variance were assessed with pairwise comparison between areas, through non-parametric Fligner-Killeen tests in "fligner.test{stats}", with Holm-alpha-adjustment using "p.adjust{stats}" (Thomas et al., 2015).

Potential associations between TCCs were tested with publicly available secondary data, including indices of multiple deprivation (IMD) (Ministry of Housing, Communities & Local Government MHCLG, 2019), and population density derived from and ward population estimates (ONS, 2021b) divided by area (ONS, 2019b). IMD is a multi-faceted summary metric encompassing aspects of employment, health, education, and crime (ONS, 2013). Accurate data linkage to IMD was only possible for England, and population density for all nations but Northern Ireland.

Twenty-six English wards could not be linked to IMD or density. Both Pearson's and non-parametric Spearman's rank coefficients were run using "cor.test{stats}" to cover discordant recommendations for correlations with non-normally distributed variables (McDonald, 2009; Thomas et al., 2015). Correlation tests were conducted within the constituent countries of the UK, because of non-equivalence in calculation methodologies between the countries (ONS, 2013, 2015). Full analytical methods description and supporting references have been described by Sales et al. (2021). Full model parameters and results are in Tables A1 and A2.

Results

Table 1 summarises descriptive statistics for TCC across the UK and its constituent countries; Table 2 summarises the nine English regions. The results are detailed in the following sub-sections. Figure 1 is a choropleth map displaying all the UK's urban wards coloured by TCC aggregations.

Constituent country statistics

The mean TCC across all urban wards in the UK was 17.3 ± 0.1% (Figure 2a). Within countries, TCC were 11.8 ± 0.5%, 15.7 ± 0.5%, 17.5 ± 0.2%, and 18.1 ± 0.5%, for Northern Ireland, Scotland, England, and Wales, respectively. Statistically, Northern Ireland's mean TCC was significantly lower than those of the other countries ($\chi^2_{(3,\ 5745)} = 122$, $p < .001$; Figure 2b; Table A1), and Northern Ireland also had the lowest median (Table 2). Wales had the highest mean and median (Table 2); the mean was not significantly different from those for Scotland and England (Table A1).

England had the highest number of wards and had the largest range of TCC, with the difference between the highest and lowest ward-level TCC being 80.4%. Scotland had the fewest wards and had the smallest range (46.2%). Wales had the highest interquartile range of TCC, 11.3%, whereas Scotland the lowest, 6.5%. The variance of urban ward-level TCC was significantly different between the four countries ($\chi^2_{(3,\ 5745)} = 52$, $p < .001$; Figure 2b); Welsh ward TCCs were the most dispersed, followed by English, then jointly by Irish and Scottish.

England regional statistics

Ward-level TCC significantly differed between the nine English regions ($\chi^2_{(8,\ 4902)} = 325$, $p < .001$; Figure 2c; Table A1). The South East has more canopy cover than the other regions, with a mean TCC of 22.1 ± 0.4%. Yorkshire, the West Midlands, and London also had high mean TCC compared with other regions, all with more than 17%. East Midlands and the South West had the lowest mean TCC with 15.0 ± 0.3% and 15.7 ± 0.6%, respectively.

Table 1. Descriptive statistics for the urban tree canopy cover percentages (TCC) for the UK and its nations. Abbreviations: N, sample size; SE, standard error; CI95, 95% confidence interval.

	N		% Canopy Cover										
			Arithmetic			Area-weighted							
Nation	Electoral wards	County/ LA	Mean	SE	CI95	Mean	SE	CI95	Max	Min	Median	25th Percentile	75th Percentile
UK	5749	383	16.5	0.5	1.1	17.3	0.1	0.3	80.4	0	15.3	11	20.6
England	4911	326	16.7	0.6	1.2	17.5	0.2	0.3	80.4	0	15.5	11.3	20.7
Northern Ireland	253	11	11.7	1.7	3.3	11.8	0.5	0.9	32	2.1	10.5	7.8	14.6
Scotland	94	24	15.7	1.1	2.1	15.7	0.5	1.1	26.7	2.6	15.6	12.3	18.8
Wales	490	22	16.9	1.8	3.6	18.1	0.5	0.9	46.5	0.3	15.5	10.7	22

Table 2. Descriptive statistics for the tree canopy cover percentages (TCC) for UK nations' regions. Abbreviations match those in Table 1.

		N		% Canopy Cover										
				Arithmetic			Area-weighted							
Nation	Region	Electoral wards	County/LA	Mean	SE	CI95	Mean	SE	CI95	Max	Min	Median	25th Percentile	75thPercentile
England	East Midlands (E Mid)	536	40	14.6	1.9	3.6	15	0.3	0.6	39.4	2.7	13.9	10.6	17.4
	Eastern (E)	562	47	16.3	2.5	4.8	16.6	0.4	0.9	80.4	1.3	15.3	11	20.5
	London	645	33	16.1	1.3	2.5	18.3	0.4	0.8	46.7	0	15.1	11.3	20
	North East (NE)	241	12	16	2	4	16.3	0.6	1.1	45.3	2.3	14.7	11	19.6
	North West (NW)	647	39	15.8	1.4	2.7	15.9	0.3	0.7	57.4	0.3	15.4	11.3	19.9
	South East (SE)	946	67	20.4	2.2	4.4	22.1	0.4	0.8	62.7	3	19.5	13.2	25.9
	South West (SW)	560	37	14.7	1.8	3.5	15.7	0.6	1.2	43.2	1	13.7	9.9	19
	West Midlands (W Mid)	538	30	16.8	1.8	3.5	17.4	0.5	0.9	46.8	4.7	15.8	12	20
	Yorkshire and Humber	236	21	16.9	1.7	3.3	17.3	0.5	0.9	38.1	4	16.3	12.7	20.3
Scotland	North (N)	21	7	15.9	2.3	4.5	16.4	1.4	2.8	26.6	6	17	12.8	18.8
	South (S)	73	17	15.6	1.2	2.3	15.6	0.6	1.1	26.7	2.6	15.5	12.3	18.8
Wales	North (N)	166	8	16	2.9	5.7	15.6	0.7	1.4	43.7	0.3	15.2	10.3	20.4
	South (S)	324	14	17.4	2.2	4.3	19.2	0.6	1.2	46.5	0.7	15.9	11.1	22.8

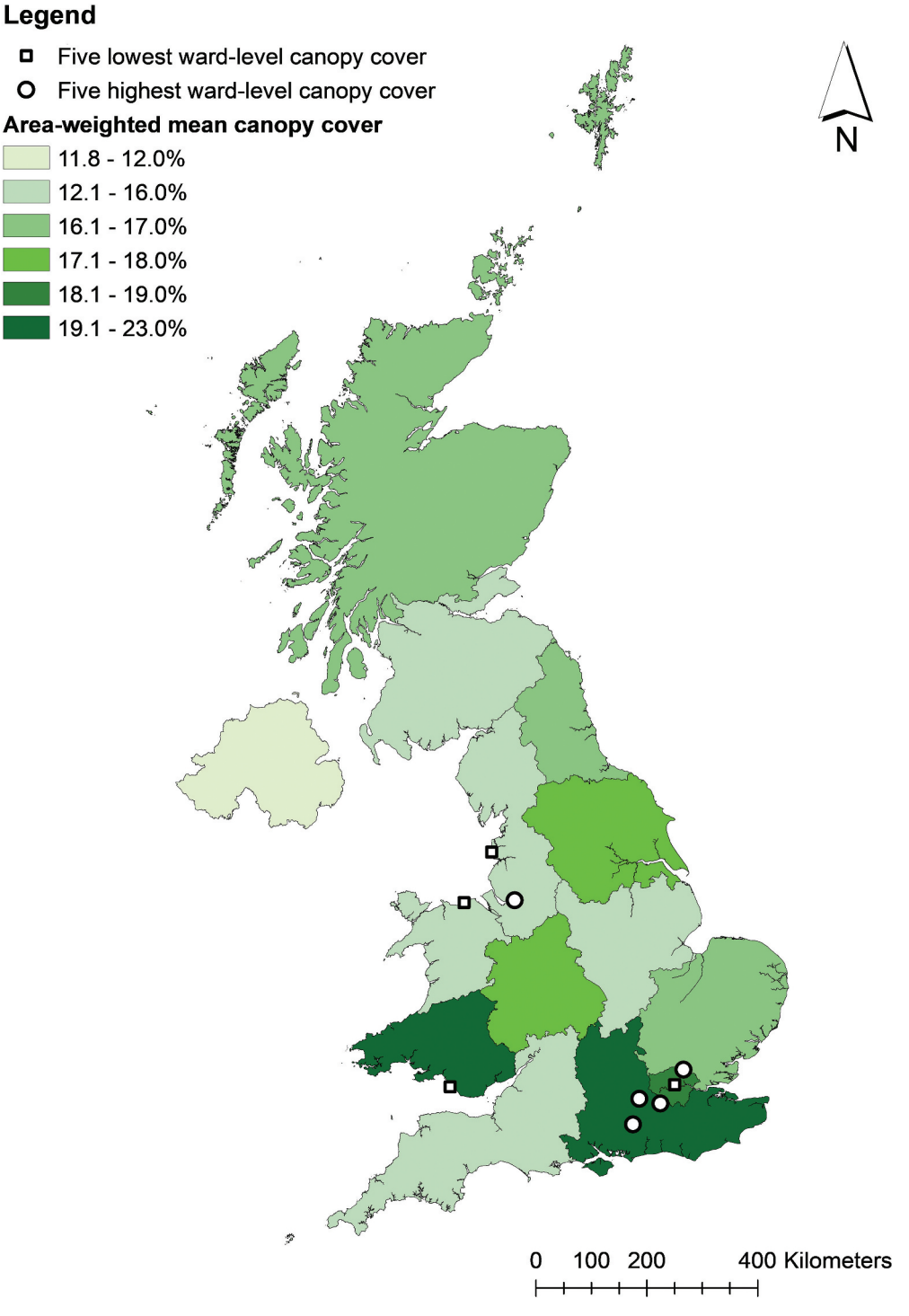
Legend
Five lowest ward-level canopy cover
Five highest ward-level canopy cover
Area-weighted mean canopy cover
11.8 - 12.0%
12.1 - 16.0%
16.1 - 17.0%
17.1 - 18.0%
18.1 - 19.0%
19.1 - 23.0%
N
0 100 200 400 Kilometers

Figure 1a.

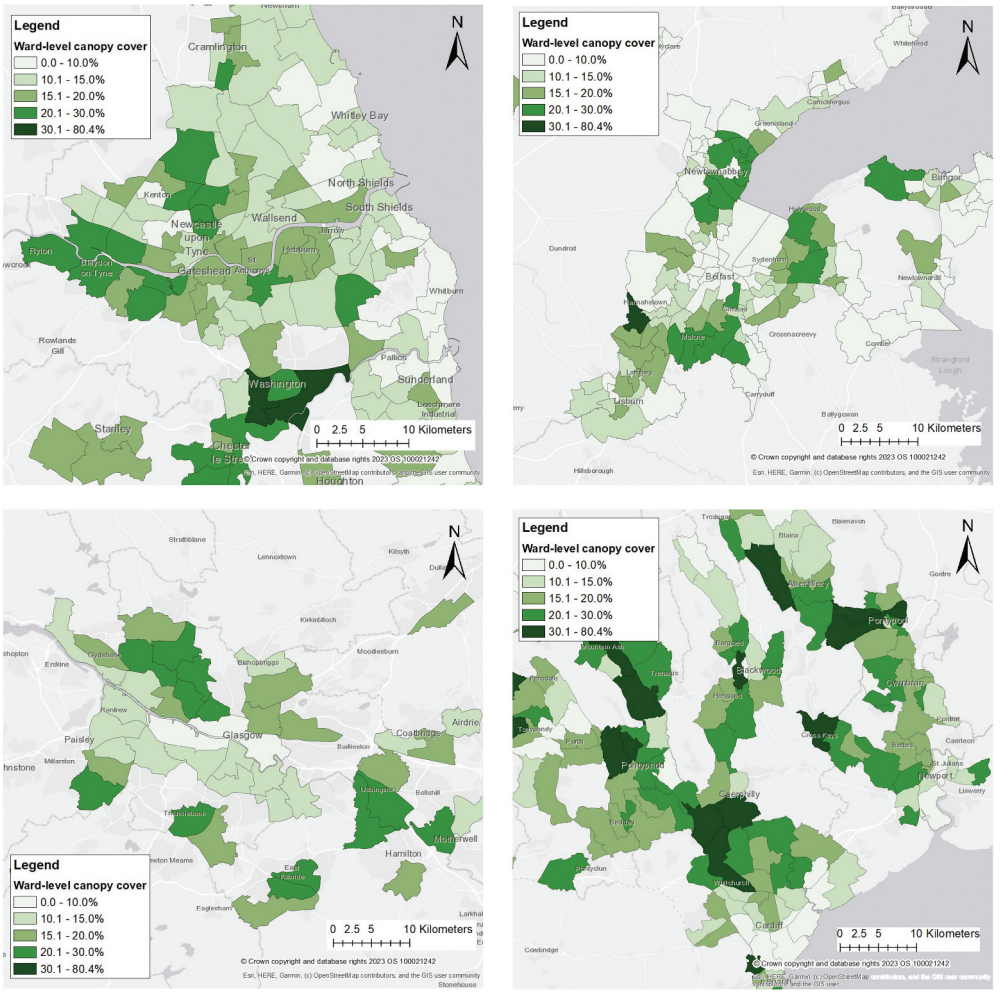

Figure 1b. Maps of tree canopy cover percentage (TCC). a) TCC of UK regions as well as the highest and lowest ward-level TCC locations. b) Ward-level TCCs of selected urban areas; clockwise from top left, Tyneside, Belfast, Cardiff and Newport, then Glasgow.

Scotland regional statistics

Ward-level TCC was not significantly different between the two Scottish regions ($\chi^2_{(1, 92)} = 0$, $p = 0.910$; Figure 2d; Table A1), with means of 16.4 ± 1.4% and 15.6 ± 0.6% corresponding to North and South.

Wales regional statistics

Ward-level TCC was not significantly different between the two Welsh regions ($\chi^2_{(1, 488)} = 3$, $p = 0.073$; Figure 2e; Table A1), with means of 15.6 ± 0.7% and 19.2 ± 0.6% for the North and South, respectively.

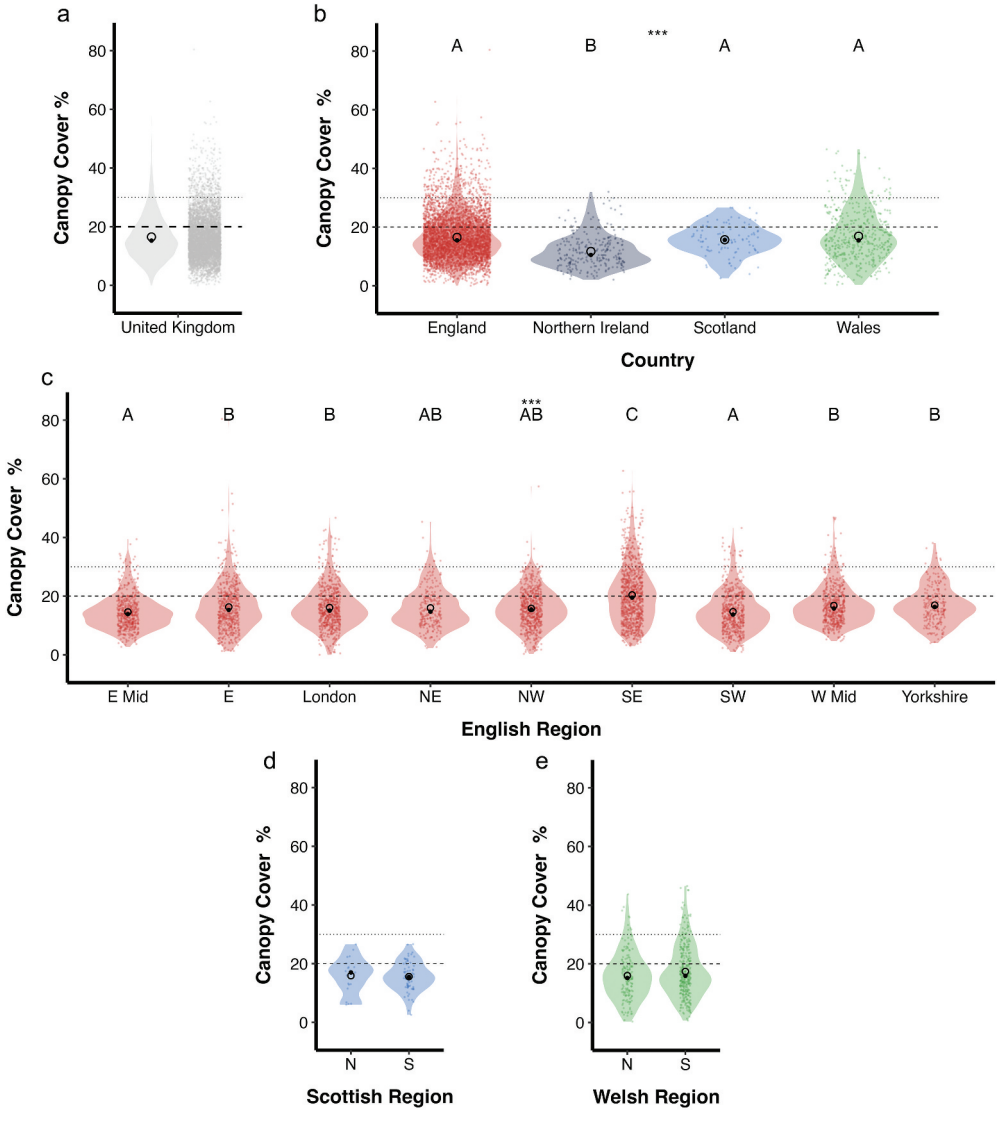

Figure 2. The distribution of tree canopy cover percentages (TCC) for urban electoral wards. In violin plots the width of the shaded area is proportional to the number of data points at a specific TCC. Medians and area-weighted means are indicated by black points and hollow rings, respectively. The dashed line indicates the proposed 20% TCC target for UK urban settlements, the dotted line shows the 30% European urban TCC target. Statistically significant differences in means between groups are indicated by letters. *** indicates $p < .001$. a) TCC across the UK, b) TCC for UK countries, and regional TCCs for c) England, d) Scotland, e) Wales. Refer to Table 1's Electoral Ward N for sample sizes underlying groupings, and abbreviations.

Local Authority (LA) statistics

Urban wards were grouped into 383 local authorities (LA) across the four countries, and summary statistics drawn. The mean TCC of Edinburgh, Belfast, Cardiff, and Greater

London were 12.6 ± 1.1%, 14.2 ± 1.5%, 17.5 ± 1.7%, and 18.3 ± 0.4%, respectively. Surrey Heath had the highest mean TCC at 42.4 ± 1.7%. Waverley, Hart, Bracknell Forest, Tandridge, Mole Valley, and Mid Sussex also had some of the highest mean TCC, ranging from 31.3 ± 2.6% to 35.3 ± 2.9%. These local authorities are all located in the South East region. The mainland LA with the lowest mean TCC of 3.8 ± 0.6% was the City of London, comprising 24 wards in the centre of London. Blackpool, Weymouth, Portland, Hartlepool, Great Yarmouth, Sedgemoor, and Tendring also featured in the lowest mean TCCs, ranging from 6.5 ± 1.1% to 8.2 ± 1.5%. These low-canopy LAs are spread across several regions, and most are coastal. Descriptive statistics for the TCC of the wards in each authority are presented in Appendix Table A3.

The TCC of most LAs falls below the previously suggested target of 20% (Doick et al., 2017), with only 22.5% of local authorities exceeding the target. England had the highest proportion of LAs (23.6%) that exceeded the 20% TCC recommendation. Conversely, Northern Ireland did not have any LAs with TCC above 20%. In Wales 22.7% of local authorities surpass the 20% target, and in Scotland 16.7%.

Ward statistic

The highest ward-level TCC was 80.4%, in Loughton St John's, which is part of Epping Forest District to the north-east of London. Grayshott, near the Hampshire-Sussex-Surrey border, also had a very high TCC of 62.7%. Of the wards with TCC above 50%, all were located in England and half were in the South East. Conversely, Langbourn, near the Tower of London had a TCC of 0.0%. Bloomfield in central Blackpool, and Rhyl West on the North Wales coastline had very low TCC at 0.3%. All the wards with 1% TCC or below were in England and Wales, and half were situated in London. The median TCC of 15.3% was shared by 37 wards, with representatives from all English regions, and Wales.

Correlations were drawn between TCC and publicly available socio-economic data at the ward level, within countries (see Appendix Table A2 for details). In England, IMD had a weak negative correlation with TCC ($t_{(4883)} = -17$, $p < .001$, $r_p = -0.2$; Figure 3a); meaning that wards with less canopy were also more likely to be deprived (Figure 3a). TCC was not correlated with population density in Scotland ($t_{(92)} = -1$, $p = 0.070$), conversely weak-moderate negative correlations were observed in England ($t_{(4883)} = -11$, $p < .001$, $r_p = -0.2$), and Wales ($t_{(488)} = -6$, $p < .001$, $r_p = -0.3$); meaning that less canopied wards were likely to be more populous (Figure 3b).

Discussion

This research describes the canopy cover data gathered by citizen scientists for the urban areas of the UK, grouping at a range of spatial scales. Three broad findings were clear from the data analysis: i) the TCC of most wards and LAs fell short of the suggested canopy cover target of 20% (Doick et al., 2017), ii) there is statistically significant variation in TCC between countries, and between regions in England, but not in Scotland or Wales, and iii) TCC was inequitably distributed across all the UK urban areas.

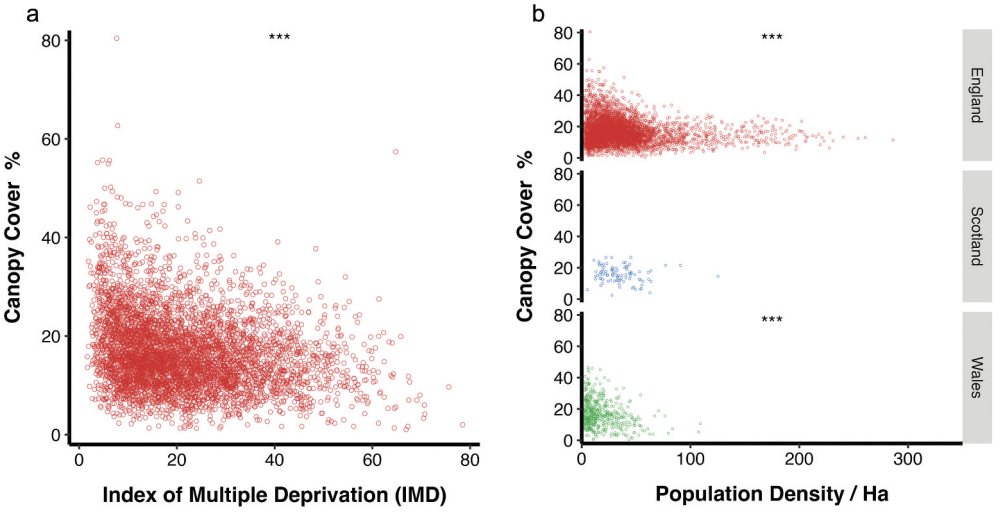

Figure 3. Scatterplots correlating urban ward tree canopy cover percentages (TCC) with publicly available socio-economic data. The statistical significance of correlation tests is indicated by: ***, $p < .001$. a) TCC correlated with English Index of Multiple Deprivation (IMD). Higher IMD scores indicate more deprived areas..[2]. b) TCC plotted against population density per panelled by nation.

Webmap TCC values relative to previous studies and future targets

Apart from the South East region of England, mean TCC for any single country or region did not exceed the minimum 20% TCC target for UK settlements (Doick et al., 2017). England had the highest proportion of LAs reaching the 20% target (23.6%), followed by Wales (22.7%) and Scotland (16.7%). No LAs in Northern Ireland met the TCC target. Canopy cover target setting is becoming increasingly commonplace and ambitious; for example a target of 30% TCC has been recommended for new development land in the UK (Reid et al., 2021), and internationally for every neighbourhood (Konijnendijk's, 2022). This data highlights that many UK LAs fall below these ambitions, with only 2.4% of LAs having a TCC above 30%.

The UK's overall urban TCC of 17.3% is suboptimal relative to many international baselines larger than the UK's non-statutory 20% target. For example, a 2018 database of 1000 cities across 38 European countries summarises average TCC as 30.2% (European Environment Agency EEA, 2021). In this European database, the UK is the best sampled country with 130 cities measured, but has the seventh worst ranking for mean urban TCC. TCC values between this European evaluation and the Webmap are similar, with central London having the lowest canopy cover of any city centre in Europe. Previous research on cities across the globe concluded that targets typically represent an increase of 0.2–0.8% per year over 20–25 years, or an average rate of 0.4% per year (Doick et al., 2017). If this projection was applied to present (Webmap) TCC in the UK it would likely take 5, 6, 11, and 20 years for Wales, England, Scotland, and Northern Ireland to, respectively, reach the putative UK urban canopy target of 20%.

Geographical variation in TCC and its correlation with deprivation

There were statistically significant differences in TCC at the national and regional geographic scales. Of the nine English regions, the South East was the most canopy-rich, while the North East and South West were the least. There were no significant regional TCC differences in Scotland or Wales; however, the power of these analyses may be constrained by the lower number of wards in these nations. There was considerable variation of canopy cover at the electoral ward scale, even over short distances; the highest TCC, 80.4%, and lowest, 0%, were both in the Greater London Area boundary. Correlations revealed that wards with lower TCC were more likely to be deprived in England, and more likely to be densely populated in England and Wales. Localised UK canopy cover studies have similarly identified TCC's relation to deprivation, and its sub-categories, for example in High Wycombe and Plymouth (Treeconomics, 2023), and in Welsh urban areas ($N = 220$) (Natural Resources Wales NRW, 2016). The association of social vulnerability with low green infrastructure is paralleled in international research (Konijnendijk, 2022).

Low canopy cover is unlikely to be the cause of deprivation, or *vice versa*; rather the link is more likely due to underlying variables such as financial investment in an area and property prices. Nonetheless, it is inequitable and means that demographics in need of urban tree ES are less likely to receive them. These findings add to similar studies: that people living in areas of higher deprivation have less accessible greenspace in their local area (Defra, 2018), face greater flood risk (Lindley et al., 2011), are more exposed and susceptible to air pollution (Pye et al., 2006), and are subjected to higher urban mean and extreme temperatures (Lindley et al., 2011). Ecosystem services provided by trees can help to alleviate some of the social and environmental pressures experienced by people living in areas of deprivation by removing and dispersing air pollutants, cooling the local environment, reducing surface flooding, increasing access to greenspace, and encouraging active travel. The return on local per capita benefits of trees can be maximised if strategies prioritise such derived, and densely populated, areas.

Future direction

The descriptive statistics presented here are a first-look at broad patterns in the TCC data. In future, UK-wide and national analyses could progress to models which characterise longitudinal patterns in urban green infrastructure, identify underlying covariates with, and predict likely benefits and costs from TCC. Models could combine TCC with data describing climate, topography, land use, demography, socioeconomics, history, and politics. With such information the maximum, optimum, minimum, and potential rates of change in TCC could be identified for effective and sustainable ES delivery across specific locations. Developed over several years, the Webmap has started to provide valuable information highlighting opportunities for change, and for informing TCC targets. For example, Shropshire Council (2023) used the TCC, health, land ownership, flood, and deprivation data to create a tree planting and opportunities heat map aiming to optimise benefits from planting strategies in conjunction with housing associations and wildlife trusts. Target-setting for TCC based upon locally relevant baselining is considered good practice by the US Conference of Mayors, the

US Department of Agriculture FC, and various not-for-profit organisations (Doick et al., 2017; Konijnendijk, 2022).

There are multiple examples of tree targets in the UK, and beyond, not linked to the Webmap, including Bristol's "One City Plan" to double TCC by 2045 (Walters & Sinnet, 2021), Greater Manchester's City of Trees' aim to plant three million trees over 25 years (Bell, 2017) and the EEA's target of three billion trees by 2030 (European Environment Agency EEA, 2021). Longitudinal studies on urban TCC are an essential tool to assess progress towards such targets and the effectiveness of their delivery policies, yet are limited (NRW, 2016; Doick et al., 2020; World Resources Institute WRI, 2022) and vary in methodology and geographical scope. The Webmap is not a longitudinal study, rather a snapshot, but it has the advantage of being comprehensive across the UK and offers a consistently derived baseline. Repeat measurements using the same approach would provide valuable insight, but such an undertaking has drawbacks. It required substantial human resource over 5 years to complete the current (urban) Webmap and it is possible that – if repeated – appetite for participation would decrease over time. Changing definitions of "urban", and the movement of ward boundaries, may also limit comparison between time points without careful methodological control. The age of aerial imagery in the i-Tree Canopy tool is unknown to users, and it is unknown when it will be updated (it would be a significant advancement to the tool if it reported image metadata). As much of the underlying Webmap data is archived and available under a Government Open Data license it may be possible to utilise it in future change monitoring, alongside additional data sources. High resolution remote-sensed data combined with machine learning techniques and field-data for verification and accuracy checking provide optimism for a cost-effective approach to repeat measurement (for example, the Copernicus Land Monitoring System; EEA, 2021).

Further to longitudinal studies, future work may also consider deep-dive analysis of geographic patterns. For example, previous research has identified coastal urban areas as having a lower TCC, for example the average TCC of coastal towns was 2.7% less than inland ones (Doick et al., 2017). Anecdotally, the Webmap supports this observation: none of the 10 LAs with the highest canopy cover were adjacent to the coastline, but six of the 10 with the lowest canopy cover were. Detailed investigation of urban coastal canopy cover controlling for potential covariates would be worthwhile.

Key messages

This study represents the most comprehensive, fine-resolution measurement of tree canopy cover (TCC) in the UK's urban electoral wards. Three overarching findings were that:

(i) The mean TCC of towns and cities in the UK was $17.3 \pm 0.1\%$. Most urban TCCs fell short of proposals for a 20% target, and are low compared to non UK targets.
(ii) TCC significantly varied across all the considered geographical scales: electoral ward, LA, region, and country.
(iii) More deprived wards were more likely to have low canopy cover.

Existing tree canopy cover is unevenly distributed geographically and demographically. Canopy cover targets could be higher and take account of land use, plantable space, and the current inequitable distribution. The data in this study, down to the electoral wards level, are now openly available and may be linked to other datasets to help inform equitable planting policy, urban forest management, and public engagement.

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Data availability statement

The data that support this study's findings are available from Forestry Commission Open Data (https://www.gov.uk/guidance/access-forestry-commission-datasets).

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Appendix

Table A1. Summaries of generalised linear models (GLM) comparing canopy cover (TCC) between different geographical areas. 1. R^2 indicating the amount of variation in the response variable explained by the model, calculated as pseudo-R^2 (*from* Thomas et al., 2015). 2. Analysis of deviance testing: whether removal of a factor reduces the fit of a model and explains less variation in the response variable, calculated using log-likelihood ratio χ^2 tests (Thomas et al., 2015). 3. Degrees of freedom (Df) (numerator, denominator): numerator, the number of factor levels – 1; denominator, the sample size minus the numerator. 4. Significance of factor calculated by analysis of deviance: P-values from "drop1{stats}" (Thomas, et al., 2015; the R Core Team 2017). 5. Parameter estimates from model indicating the effect size. A negative sign indicates for a pair that the group listed on the left is less than the group top. For a particular level estimate calculation: logit-link GLM, = exp(beta(± any level modifiers))/(1 + exp(beta(± any level modifiers))). 6. Difference testing between factor levels were calculated as z statistics. 7. P-values for associated calculated by "summary{model}" (Crawley, 2013).

	GLM Model			Analysis of deviance			Post hoc comparisons (Beta parameter estimate[5], z test statistic[6], *p* value[7])				
	Error Distribution	Link function	R-square.[1]	x^2 Test statistic.[2]	Df.[3]	*P* value[4]		England	Northern Ireland	Scotland	Wales
Country Comparison – TCC central tendency	Quasi binomial	Logit	2%	122	3 5745	**<.001**	England		0.4 10 **<.001**	0.1 1.2 0.6	0 −0.7 0.912
							Northern Ireland			−0.3 −4.7 **<.001**	−0.4 −9 **<.001**
							Scotland				−0.1 −1.4 0.485
							Wales				

(*Continued*)

Table A1. (Continued).

	GLM Model			Analysis of deviance			Post hoc comparisons (Beta parameter estimate[5], z test statistic[6], *p* value[7])									
	Error Distribution	Link function	R-square.[1]	x^2 Test statistic.[2]	Df.[3]	*P* value[4]		England	Northern Ireland	Scotland	Wales					
English Region Comparison – TCC central tendency	Quasi binomial	Logit	6%	325	8 4902	**<.001**	E Mid	E Mid	E −0.1 −3.8 **0.004**	London −0.1 −3.5 **0.016**	NE −0.1 −2.5 0.223	NW −0.1 −2.8 0.112	SE −0.4 −13.8 **<.001**	SW 0 −0.3 >0.999	W Mid 0 −0.3 **<.001**	Yorkshire −0.2 −4.2 **0.001**
							E			0 0.5 >0.999	0 0.5 >0.999	0.4 1.2 0.962	−0.3 −9.9 **<.001**	0.1 0 **0.012**	0 −1.3 0.946	0 0.1 0.962
							London				0 0.1 >0.999	0 0.7 0.999	−0.3 −10.9 **<.001**	0.1 3.2 **0.043**	−0.1 −1.8 0.687	−0.1 −1.6 0.811
							NE					0 0.4 >0.999	−0.3 −7.7 **<.001**	0.1 2.3 0.362	−0.1 −1.5 0.876	−0.1 −1.4 0.895
							NW						−0.3 −11.7 **<0.001**	0.1 2.5 0.236	−0.1 −2.5 0.256	−0.1 −2.1 0.474
							SE							0.4 13.7 **<.001**	0.2 8.4 **<.001**	0.2 6 **<.001**
							SW								−0.2 −4.8 **<.001**	−0.2 −3.9 **0.003**
							W Mid									0 −0.2 >0.999
							Yorkshire									
Scottish Region Comparison – TCC central tendency	Quasi binomial	Logit	1%	0	1 92	0.91	North	North	South 0 0.1 0.91							
							South									
Welsh Region Comparison – TCC central tendency	Quasi binomial	Logit	1%	3	1 488	0.073	North	North	South −0.1 −1.8 0.074							
							South									

Table A2. Summaries of correlation tests between canopy cover (TCC) and either the Index of Multiple Deprivation (IMD) score or population density. Pearson's statistics reading from top: test statistic (t), degrees of freedom (Df), *p* value, correlation coefficient (r_p). Spearman's statistics reading from top: test statistic (S), Df, *p* value, correlation coefficient ($r_{s.}$).

		Pearson's Correlation				Spearman's rank Correlation			
		IMD	Population			IMD	Population		
		England	England	Scotland	Wales	England	England	Scotland	Wales
Canopy Cover	England	−17	−11			2.00E + 10	2.00E + 10		
		4883	4883			4885	4885		
		<.001	**<.001**			**<.001**	**<.001**		
		−0.2	**−0.1**			**−0.1**	**−0.2**		
	Scotland			−1				2.00E + 05	
				92				94	
				0.2				0.07	
				−0.1				−0.2	
	Wales				−6				2.00E + 07
					488				490
					<.001				**<.001**
					−0.3				**−0.2**

Table A3. The tree canopy cover percentages (TCC) of 383 County and Local Authorities (LA) in the UK. Abbreviations: N, sample size; SE, standard error.

		Arithmetic		Weighted				
County/LA	N Electoral wards	Mean	SE	Mean	SE	Max	Min	Median
Aberdeen City	7	14.9	6.4	14.9	2.4	22.3	6.3	17
Adur	14	10	3.5	10.3	0.9	18.3	5.5	9.9
Allerdale	13	14.8	4.1	15.7	1.3	22.3	8.3	14.4
Amber Valley	16	15.2	3.8	16.3	0.9	22.6	8.2	15.1
Antrim and Newtownabbey	26	13.4	6.8	13.4	1.8	25.9	4	11.9
Ards and North Down	27	9.7	5.4	10.2	1.7	21.8	2.1	8.7
Argyll and Bute	1	22.5	NA	22.5	NA	22.5	22.5	22.5
Armagh City Banbridge and Craigavon	17	10	3.4	10.5	1	16	4.9	9.3
Arun	19	10.8	3.5	10.1	1.1	16.9	4.3	10.8
Ashfield	20	13.1	4.7	13.4	1.1	21.2	5.8	12.7
Ashford	20	17.9	8.6	21.9	3.2	38.2	7.2	16.2
Aylesbury Vale	11	10.6	2.7	9	1.4	14.8	4.8	10.2
Babergh	7	19.3	3.4	17.8	1.4	24.6	15.4	19.3
Barking and Dagenham	17	9.2	3.9	8.8	1.4	15.8	3	8.7
Barnet	21	19.6	5.4	20.7	1.4	28.7	12.5	18.7
Barnsley	15	20.1	6.9	20.2	1.9	36.3	11.3	18.1
Barrow-in-Furness	11	9.6	5.1	8.9	2	17.7	1.7	8.3
Basildon	13	18.3	7.8	18.7	2.5	34.5	7.7	19.6
Basingstoke and Deane	17	20.6	5.8	21.3	1.8	34.3	10.8	20
Bassetlaw	8	13.8	6.1	12.4	2.3	25.7	6.7	13.1
Bath and North East Somerset	28	19.7	6.4	18.6	1.5	36.9	9	19.2
Bedford	17	12.7	4.4	12.4	1	23.8	5.9	11.7
Belfast	60	13.4	7.1	14.2	1.5	32	4	12
Bexley	17	14.5	4.9	16	1.6	28	7	14.3
Birmingham	67	21.1	7.6	22.5	1.1	46.8	9.7	20
Blaby	12	14.2	3	14	0.9	20.6	10.2	13.9
Blackburn with Darwen	14	14.3	5.3	15.1	1.8	27.6	9.3	12
Blackpool	21	5.1	3.9	6.5	1.1	13.7	0.3	3.7
Blaenau Gwent	14	15.8	8.1	16.4	2.6	32.3	6.8	13.4
Bolsover	13	14.2	5.3	14.1	1.7	24.7	5.7	13.5
Bolton	15	18.1	5	18.8	1.4	28.6	8.9	18
Boston	8	12.5	1.7	13	0.5	13.7	9.3	13.3
Bournemouth	18	18	7.3	18	2	38.1	7.9	15.7
Bracknell Forest	14	31.3	10.7	34.4	3.4	50.2	14.2	28.8
Bradford	20	16.6	6.7	17.2	1.8	33	7.3	14.9
Braintree	11	8.4	3.1	8	1	14	4	8.6

(*Continued*)

Table A3. (Continued).

County/LA	N Electoral wards	Arithmetic		Weighted				
		Mean	SE	Mean	SE	Max	Min	Median
Breckland	7	21.2	9.1	19.2	4.2	33	9.3	21.6
Brent	21	13.7	4.6	13.7	1.1	23.1	6	13.7
Brentwood	9	22.5	7.4	19.9	2.7	38.2	13.3	21.7
Bridgend	29	17.3	8.1	18.8	1.7	32.7	0.7	15.7
Brighton and Hove	20	12.9	7.2	14.5	2.5	35.1	4.6	10.4
Bristol, City of	33	17.7	5.9	18.6	1.1	29.3	9.1	17
Broadland	12	19.6	7.2	18.1	2.3	36.5	12	17.1
Bromley	17	23.8	4.5	24.2	1.3	33.3	14.3	23.4
Bromsgrove	24	16.7	9.6	20.6	3.1	40.8	7.3	13.1
Broxbourne	9	19.9	9.6	22.3	3.6	35.2	7.1	16.3
Broxtowe	18	14.9	4.7	15.8	1.5	25.6	7.7	14.1
Burnley	11	20.3	3.6	20.2	1.2	27.5	15.7	19.5
Bury	16	19.1	7.5	19.3	2	38.5	9.8	17.2
Caerphilly	21	19.8	8.9	21	2.3	45.1	6.5	19.6
Calderdale	8	21.5	4.6	21.4	1.6	29.9	16.6	19.7
Cambridge	14	16.1	2.5	16.3	0.9	21.2	12.4	15.6
Camden	18	19.8	8.3	22.8	2.7	40.5	10	18.5
Cannock Chase	12	18.4	7.9	21.7	3.1	32.2	10.6	15.3
Canterbury	12	14.6	6.8	17.5	2.3	24.8	3.8	12.9
Cardiff	27	15.5	7	17.1	1.7	32.8	5.3	14.8
Carlisle	12	14.6	3.6	15.7	1.1	20.8	9.3	13.8
Carmarthenshire	15	13.7	6.2	16.2	2	25.9	3.9	13.8
Castle Point	14	14.2	13.1	16	4.8	38.2	1.3	11.6
Causeway Coast and Glens	16	11.5	5.5	10.9	1.8	24.4	2.6	12.5
Central Bedfordshire	12	13.1	5.1	13.7	2	21.2	5.5	12.8
Ceredigion	14	14.8	7.4	13.7	2.2	27.6	4.5	13.1
Charnwood	21	14.9	5.9	15	1.6	32	6.6	13.5
Chelmsford	16	12.5	4.1	11.7	1.2	19	5.3	13.4
Cheltenham	20	13.7	4.7	14.1	1.3	23	7	12.9
Cherwell	8	13.8	2.6	13.1	1.3	18	8.4	14
Cheshire East	33	17	6.2	17.7	1.2	29.5	5.7	16.7
Cheshire West and Chester	25	15.7	5.3	16.8	1.3	30.2	6.3	16.1
Chesterfield	18	15.8	4.9	16.3	1.4	25.8	8.8	14.9
Chichester	12	12.3	5.6	11.4	2.1	22	6.5	11.8
Chiltern	19	27.1	6.7	28.3	1.7	39.6	16	27.2

(*Continued*)

Table A3. (Continued).

		Arithmetic		Weighted				
County/LA	N Electoral wards	Mean	SE	Mean	SE	Max	Min	Median
Chorley	13	25.1	6.4	23.1	2.1	36.2	12.7	25.5
Christchurch	10	19.5	9.5	17.1	4.3	35.2	8.9	15.4
City of Edinburgh	12	12.7	3.6	12.6	1.1	18	7	12.3
City of London	24	3.4	2.7	3.8	0.6	11.7	0	3.2
Clackmannanshire	1	16.9	NA	16.9	NA	16.9	16.9	16.9
Colchester	13	15.8	4.4	16.1	1.4	28.2	10.6	14.6
Conwy	25	14	7.4	13.8	1.7	26.7	0.8	14.9
Copeland	16	14	7.1	13.4	2.2	28.8	2.7	11.8
Corby	10	17.2	10.3	18.2	3.9	37.7	7	12.6
Cornwall	59	12.4	5	15.7	2.2	21.6	1.7	12.6
Cotswold	10	10.6	4.9	10.7	1.7	16.3	1.3	10.8
County Durham	27	20.5	8	20.1	1.6	39.9	9	18.8
Coventry	17	14.6	5.3	15.4	1.3	25.8	7.6	14.6
Craven	6	12.8	7.8	12	3.3	26.6	7	9.8
Crawley	14	28.6	9.9	28.7	3.3	49.1	15	24.1
Croydon	28	22.2	11.1	27.1	2.5	46.7	9.2	18.4
Dacorum	18	19.6	4	19.2	1	27.4	12.5	19.9
Darlington	17	17.2	6.4	15.7	2.2	30.9	7.6	17.4
Dartford	15	16.3	6.7	16.6	2.1	30.7	7.7	15.3
Daventry	4	17	2.3	17	1.2	19.3	14.9	16.9
Denbighshire	16	8.6	6.1	9.5	1.5	19.3	0.3	8.4
Derby	17	14.5	5.1	15	1.3	26.2	2.7	15
Derbyshire Dales	3	15.6	1.7	15.9	1.1	17.6	14.3	15.1
Derry City and Strabane	26	10.3	3.1	10.7	0.8	17.3	4.7	10.4
Doncaster	8	13	4.1	13.3	1.5	20.8	8.9	11.9
Dover	12	20.3	8.9	19.2	2.9	39.1	10.5	18.4
Dudley	24	20.5	4.4	20.7	0.9	30	11.8	19.2
Dumfries and Galloway	1	13.3	NA	13.3	NA	13.3	13.3	13.3
Dundee City	5	13.8	4.9	14.6	2.1	18.5	6.3	16
Ealing	23	16.8	4.9	17.2	1	25.9	6.4	16.2
East Ayrshire	2	11.6	4.3	11.9	3	14.6	8.6	11.6
East Cambridgeshire	3	9.6	3.2	8.7	1.6	13	6.7	9
East Devon	11	14.4	7.8	15	2.1	30.2	4.7	13.6
East Dorset	8	24.6	7.2	25.8	2.7	35.6	14.4	23.7
East Dunbartonshire	3	18.3	3.8	18.6	2.1	22.4	15	17.6

(*Continued*)

Table A3. (Continued).

County/LA	N Electoral wards	Arithmetic		Weighted		Max	Min	Median
		Mean	SE	Mean	SE			
East Hampshire	23	21.8	13	25.4	4.6	62.7	8.6	17.9
East Hertfordshire	17	19.9	5.1	20	1.3	27.8	7	20.3
East Lindsey	11	11.5	4.1	9.9	1.5	18.4	5.3	11.7
East Northamptonshire	10	11.3	2.9	10.7	1	15.5	7	10.2
East Renfrewshire	2	21.1	7.6	20.4	5.4	26.5	15.8	21.1
East Riding of Yorkshire	7	15.6	6	15.5	2.3	26.6	9.7	15.3
East Staffordshire	13	13.6	4.2	13.5	1.3	21.3	8	14
Eastbourne	8	12	6.9	13.2	2.8	24.4	3.3	11.7
Eastleigh	14	25	6.2	24.9	1.5	34.5	10.7	24.7
Eden	7	15.8	4	15.1	1.7	20.6	11	14.2
Elmbridge	12	20.6	7	20.8	2.4	34.2	6.7	19.7
Enfield	19	14	6.1	13.8	1.5	26.7	5	13
Epping Forest	23	24.1	16.4	25	4.5	80.4	7.3	18.4
Epsom and Ewell	13	20.5	6.4	23.5	2.4	34	9.5	21.1
Erewash	16	14.9	4.4	15.1	1.3	24.6	9.5	13.7
Exeter	13	19.1	5.5	19.5	1.7	29.9	12.8	17.3
Fareham	14	19.9	8.7	20.4	3.5	45.5	8.3	19.3
Fenland	12	11.6	4	11.7	1.9	18	4.3	11.2
Fermanagh and Omagh	11	15.3	5.1	16	1.7	23.4	8	13.9
Fife	3	20.6	2.5	20.3	1.4	23.2	18.2	20.3
Flintshire	42	14.6	7.6	13.9	1.2	39.4	2.9	13.6
Forest Heath	5	18.3	17.6	24.1	11	49.3	8.3	9.3
Forest of Dean	8	22.8	10.2	25.9	4.9	43.2	12.3	21.3
Fylde	17	10.5	5.4	9.3	1.5	20.7	1.8	9.8
Gateshead	17	17.8	5.1	18.9	1.4	28	10.7	16.1
Gedling	14	10.8	4.9	11.2	1.3	22	4.8	9.9
Glasgow City	16	15.3	5.8	15	1.5	26.7	4	15.2
Gloucester	18	10.4	4.9	11.7	1.6	24.4	3	10.1
Gosport	17	14.6	7.6	15.6	2.1	30.5	4	12.3
Gravesham	15	12.5	7.6	16.8	4.4	36.3	3	11
Great Yarmouth	11	7.4	3	7.3	1	12.7	1.7	7.7
Greenwich	17	17.7	7.9	18.1	2.2	42.3	5.7	15.7
Guildford	13	26.3	8	26.8	2.2	38.1	15.9	25.8
Gwynedd	29	20.5	9.6	17.5	1.9	43.7	6.5	18.1
Hackney	21	14.2	4.1	14.7	0.9	21.3	6.3	14.7

(*Continued*)

Table A3. (Continued).

		Arithmetic		Weighted				
County/LA	N Electoral wards	Mean	SE	Mean	SE	Max	Min	Median
Halton	20	18.6	11.4	17	2.3	57.4	8.2	14.3
Hambleton	2	9.2	0.2	9.2	0.2	9.3	9	9.2
Hammersmith and Fulham	16	13.5	4.7	13.6	1.4	24.4	8.7	11.7
Harborough	12	11.3	5.2	10	1.5	24.3	5.2	10.2
Haringey	19	16	6.9	17.3	1.8	36	7.7	13.7
Harlow	11	19.7	6.2	19.8	2	31.4	12.3	19.5
Harrogate	27	19.1	7.2	20.3	1.6	34.7	8.9	18
Harrow	21	16.1	7	19.3	2	31.6	7.4	13.7
Hart	6	35.2	6	35.3	2.4	45	28.1	34.6
Hartlepool	8	7.9	3.5	7	1.4	13	2.7	7.4
Hastings	16	23.7	7.7	25.1	2	36.3	7.5	24.6
Havant	14	19.6	7.5	17.4	2.3	33	6.8	18.7
Havering	16	15.1	5.9	17.1	1.7	25.3	5.3	15.1
Herefordshire, County of	23	13.6	6.5	12.8	2	29	5	11.7
Hertsmere	13	19.8	7.1	21.5	2.3	31.3	10.1	17.4
High Peak	18	18.3	6.7	16.5	1.9	32.8	8.6	18.6
Highland	3	16.9	6.8	17.9	4.5	24.8	12.8	13.2
Hillingdon	20	17	6.3	17.8	1.7	31.3	6.7	15.7
Hinckley and Bosworth	9	12.8	6.4	13.1	2.7	27.6	7.6	11.2
Horsham	9	26.9	7.6	31	3.7	40.8	19.4	23
Hounslow	20	15	5	15.2	1.1	26.4	7	15
Huntingdonshire	9	11.3	5.3	12.5	2.2	20.7	4.7	13.3
Hyndburn	14	16.8	6.5	15.4	2	25.7	4.3	16.5
Inverclyde	4	17.1	4.3	17.3	2.2	21.8	12.3	17.1
Ipswich	16	17.3	4.9	17.6	1.4	27	11	16.8
Isle of Anglesey	1	12.3	NA	12.3	NA	12.3	12.3	12.3
Isle of Wight	29	18.3	7.9	20.3	1.6	33.5	5.8	17.3
Isles of Scilly	5	5.7	3.8	7.1	2.1	10	1	5.6
Islington	16	17.8	5.1	17.6	1.3	26.7	8.7	18.3
Kensington and Chelsea	18	17.7	5	18.3	1.4	33.7	13	16.2
Kettering	12	13.7	4.2	12.7	1.5	21.1	7.7	12.6
King's Lynn and West Norfolk	12	16.4	6.6	15.3	2.7	31	7.2	14.6
Kingston upon Hull, City of	21	15.1	5	14.3	1.1	32.8	10.3	13.7
Kingston upon Thames	16	16.4	6.4	18.5	2.3	34.3	10.3	14.3
Kirklees	10	20.1	4	20.4	1.3	26.6	13.3	19.4

(*Continued*)

Table A3. (Continued).

County/LA	N Electoral wards	Arithmetic		Weighted		Max	Min	Median
		Mean	SE	Mean	SE			
Knowsley	11	12.8	3.1	13	1	16.6	8.6	12.8
Lambeth	21	15.9	3.6	16.3	0.8	22.8	10	16
Lancaster	18	15	6.3	15.7	1.6	27.2	5.7	14.2
Leeds	15	18.3	7.5	18.3	2.1	29.5	8.4	19.7
Leicester	21	14.8	4.2	16.6	1	23	7.7	14.9
Lewes	15	11.5	4.7	12.2	1.5	21.7	3.7	9.8
Lewisham	18	20.4	4.2	20.4	1	26.3	13	19.9
Lichfield	12	13.1	4.3	14	1.5	20.8	6	13
Lincoln	11	15.5	7.2	15.8	2.2	31.6	10.3	11.7
Lisburn and Castlereagh	25	11.9	4.8	11.1	1.3	23.1	3.3	12
Liverpool	29	14.2	6.3	14.6	1.2	28.4	5.3	13.2
Luton	19	12.8	3.7	12.8	0.9	22.3	6.5	12.3
Maidstone	15	20.9	6	22.4	1.8	32.7	7	21.3
Maldon	6	10.5	5.5	11	2.4	16.7	3.9	10.3
Malvern Hills	6	22.3	10.3	22.3	4.5	39.7	13.4	17.5
Manchester	31	16	6.6	16.9	1.2	29.9	2.7	16
Mansfield	36	13	7.2	17.5	2	29.6	3.4	11
Medway	19	17.4	5.7	17.2	1.5	29	8.3	18
Melton	6	11.4	3.2	11.8	1.4	14.4	6.6	11.9
Mendip	17	11.6	4.2	11.3	1.3	20.5	5.7	10.3
Merthyr Tydfil	7	18.3	13.6	19.4	5.3	40	4.9	14
Merton	20	15.3	7	18.8	2.7	40	7.3	14.7
Mid and East Antrim	23	10.1	3.8	10.2	1	18.8	3.3	9.7
Mid Devon	6	10.2	4.6	11.2	2.3	16	4.3	10.2
Mid Suffolk	5	18.7	2.8	18.7	1.3	22.1	15.3	19.3
Mid Sussex	17	28.3	8.9	31.3	2.6	46.8	15	27.3
Mid Ulster	11	10.8	2.7	10.7	1	16.3	7	9.7
Middlesbrough	20	16.7	6.8	16.2	1.8	29.3	8	14.7
Midlothian	1	15.5	NA	15.5	NA	15.5	15.5	15.5
Milton Keynes	15	21.5	4.9	21.7	1.3	30.7	14.7	20.9
Mole Valley	13	32.5	9	32.7	2.5	55.6	22.5	30.3
Monmouthshire	24	16.4	8	19.9	2.3	31.8	2	15.7
Moray	2	17.6	0.1	17.5	0.1	17.6	17.5	17.6
Na h-Eileanan Siar	1	6	NA	6	NA	6	6	6
Neath Port Talbot	27	21.4	9.8	23.3	2.2	38.7	3	22

(*Continued*)

Table A3. (Continued).

County/LA	N Electoral wards	Arithmetic		Weighted				
		Mean	SE	Mean	SE	Max	Min	Median
New Forest	21	22.6	6.5	24.2	1.9	36.5	11.2	21.8
Newark and Sherwood	7	11.7	4.3	13.1	2.2	19.7	8.8	9.1
Newcastle upon Tyne	24	17.4	5.4	17.9	1.4	28	9.7	18.3
Newcastle-under-Lyme	17	17.3	6.6	18.3	2	29.8	6	17.3
Newham	20	11.4	4.5	10.9	1.3	22.1	3.7	10.7
Newport	14	15.8	6.5	17.1	2.4	25.7	5	16
Newry, Mourne and Down	11	10.1	2.7	9.6	1	16.5	7	10.5
North Ayrshire	2	9.1	9.2	11.3	6.9	15.6	2.6	9.1
North Devon	9	10.8	3.2	11.4	1.3	15.8	5.7	10
North Dorset	7	14.8	5.3	15.5	2.6	22.9	7.7	13.3
North East Derbyshire	17	18.5	4.7	18.1	1.1	30.3	13.3	17.8
North East Lincolnshire	11	12.5	4.4	13.2	1.3	19	5.3	13.8
North Hertfordshire	17	14	3.6	13.4	1	20.6	7.3	14
North Kesteven	11	8.6	2.9	8.9	1	12	4	8.7
North Lanarkshire	7	16.9	3.6	16.8	1.5	22.7	12.5	16
North Lincolnshire	6	13.5	7.1	12.7	2.8	24.8	6	12.2
North Norfolk	8	17.9	7.9	16.6	2.8	30.3	8.2	14.4
North Somerset	23	10.7	7.5	10.6	2.1	35.5	2.3	8
North Tyneside	20	12.7	3.1	12.8	0.8	18.7	6.3	12.4
North Warwickshire	11	15.1	3.6	14.8	1	22.6	9.6	15
North West Leicestershire	31	19.5	6.9	20.8	1.6	33.8	8.6	18.6
Northampton	33	16.5	6.1	16.5	1.3	34.4	7.9	14.9
Northumberland	35	17.7	8.6	17.8	2	45.3	6.7	14.9
Norwich	13	17.4	4.8	18.2	1.6	27.9	10.7	18
Nottingham	20	17.6	6.1	18.2	1.5	30.3	8.8	17.4
Nuneaton and Bedworth	15	13.3	4.3	13.1	1.3	23.8	7.2	13.2
Oadby and Wigston	10	14.1	4.5	14.1	1.7	23.8	9.4	12.9
Oldham	18	16.6	5.1	16.4	1.3	26.8	7.3	17.4
Oxford	23	21.2	6.1	20.7	1.5	34.3	9	22.2
Pembrokeshire	27	9.1	3.9	10.5	1	18.8	1.3	9.2
Pendle	16	15	5.8	13.8	1.5	28.3	5.7	15
Perth and Kinross	2	22.7	5.5	23.6	4	26.6	18.8	22.7
Peterborough	18	13.3	6.1	12.6	1.6	24.6	4.7	11.9
Plymouth	20	17	7.5	18.7	1.9	32.5	4	16.6
Poole	15	18.2	9.1	21.1	2.8	36.9	5	18

(*Continued*)

Table A3. (Continued).

County/LA	N Electoral wards	Arithmetic		Weighted		Max	Min	Median
		Mean	SE	Mean	SE			
Portsmouth	14	9.9	3.5	10.7	1	16.5	3.4	10.6
Powys	18	17.4	4.9	18.2	1.3	28.9	10.7	17.3
Preston	19	18.8	5.8	19.8	1.9	29.8	7.5	20.5
Purbeck	4	12.9	6.2	12.2	2.8	21.3	7.6	11.3
Reading	17	19	5.1	18.6	2	32.2	6.7	19.5
Redbridge	22	14.4	9.1	16.2	2.6	42.7	5.8	11.5
Redcar and Cleveland	15	12.4	7.2	13.2	2.1	28	3	11.3
Redditch	11	26.7	7.4	27	2.2	41.4	16	27.8
Reigate and Banstead	15	24.6	6.7	26.2	1.6	37	13	25.7
Renfrewshire	5	15.1	4.1	15.3	2	21.5	10.2	14.7
Rhondda Cynon Taf	41	21.8	10.7	23.1	1.9	46.5	5.1	17.8
Ribble Valley	11	14.1	2.6	13.2	1.1	16.6	8.7	15.4
Richmond upon Thames	18	20.6	7.1	23.5	2.4	39.4	9.3	19.6
Richmondshire	6	20.2	4.6	20.8	2.3	25.6	14	22
Rochdale	16	15.5	6	15.4	1.6	27.6	7.3	13.5
Rochford	8	21.2	8.4	21.9	4.1	35.8	11.3	18.2
Rossendale	8	14.5	6.7	13	2.4	24.8	7.3	13.6
Rother	9	13.6	5.1	15.7	2.9	24.2	8	12.9
Rotherham	12	17.9	4.3	18.9	1.3	26.1	11.9	16.8
Rugby	10	12.7	4	12.1	1.6	18.6	4.7	13.6
Runnymede	12	21.8	7.6	22.7	2.6	36.3	9.6	20.4
Rushcliffe	13	12.5	4.3	11	1.8	18.8	4.8	14
Rushmoor	13	25.6	9.1	29.7	3.5	39.7	13.6	25.4
Rutland	5	12.6	4.2	11.6	2	18.4	8.3	13.4
Ryedale	2	10.5	2.1	11	1.6	12	9	10.5
Salford	19	18.2	5.3	18.5	1.5	29.4	8.3	17.9
Sandwell	24	14.6	3.6	14.6	0.8	20.6	9	13.4
Scarborough	15	16	7.7	16.1	2.2	31.2	4	16.3
Sedgemoor	10	7.1	2	7.1	0.6	9.6	3	8
Sefton	17	12.4	4.2	12.8	1.2	18.7	4.2	11
Selby	3	11.5	4.6	12.6	3.2	16.8	8.7	9
Sevenoaks	13	25.6	9.4	30.7	3.8	41.7	14	23.5
Sheffield	22	19.6	6.9	19.9	1.5	38.1	4.4	17.7
Shepway	7	17.2	4.6	15.8	2.2	22.6	10	18.4
Shropshire	25	14.9	4.1	15.8	2.2	24.7	6.8	13.9

(*Continued*)

Table A3. (Continued).

County/LA	N Electoral wards	Arithmetic		Weighted				
		Mean	SE	Mean	SE	Max	Min	Median
Slough	15	13.3	4.6	14.3	1.4	23	6.3	14
Solihull	12	18.5	4.1	19.3	1.2	26	12.8	17.8
South Ayrshire	2	13.5	2.1	13.1	1.6	15	12	13.5
South Bucks	4	24.6	3.9	24.7	1.8	29.4	19.8	24.6
South Cambridgeshire	3	13	6.4	12	3.7	19	6.3	13.7
South Derbyshire	6	14.6	6.7	14.6	3	25	7.1	14.4
South Gloucestershire	22	15.1	3.5	16.2	0.9	21.2	9.3	15.2
South Hams	5	17.5	5.7	15.5	2	27.3	12.5	15.8
South Holland	6	10.9	4.4	9.6	2	17.2	3.7	11
South Kesteven	13	13.4	8.5	14.2	4.2	39.4	4.3	11.7
South Lakeland	8	14.8	5.4	10.1	3.8	22	7.4	16.1
South Lanarkshire	9	17.8	5.1	18.3	1.7	23.8	11.3	20
South Norfolk	7	15.3	3	14.2	1	19.6	12.3	14.1
South Northamptonshire	7	14.1	5.3	14	2.6	20.2	7.1	14.9
South Oxfordshire	7	17.8	5.5	17.7	2.2	26.8	12.8	15.8
South Ribble	20	18.5	5.5	17.6	1.4	28.7	11.3	17.4
South Somerset	13	11.5	4.1	12.2	1.4	21.8	7	11.5
South Staffordshire	10	15.4	3.6	14.3	1.4	21.8	9	14.5
South Tyneside	17	13.2	4.7	13.1	1.5	21.4	2.3	13.5
Southampton	16	20.1	8.9	20.1	2.3	33	6.3	22.2
Southend-on-Sea	17	8.8	3	9	0.8	17.3	4.3	8.6
Southwark	23	17.3	6.1	18.8	1.6	31.1	6.3	17
Spelthorne	12	13	3.7	13.1	1.2	19.3	8.2	12.1
St Albans	14	21.1	4.2	21.2	1.2	27.2	16.1	20.5
St Edmundsbury	14	20.8	5.9	18.4	2.6	32.2	9.4	21.4
St. Helens	12	16.9	4.7	16.8	1.6	25.8	11.4	16.1
Stafford	14	13.4	3.3	13.1	0.9	20.2	7.8	13
Staffordshire Moorlands	13	14.6	5.4	15.7	1.5	24.3	5.5	13.4
Stevenage	13	21.7	3.5	21.7	1	26.9	17.6	20.9
Stirling	1	15.9	NA	15.9	NA	15.9	15.9	15.9
Stockport	19	19.1	4.5	19.2	1.2	29.3	12	18.6
Stockton-on-Tees	20	15.1	5	14.2	1.3	26	7.7	14.5
Stoke-on-Trent	37	15	4.1	15.8	0.8	26	6.2	15.2
Stratford-on-Avon	14	11.3	3.9	10	1.1	22	5.7	10.3
Stroud	16	22.4	9.5	25.5	2.8	36.8	8.9	22.2

(*Continued*)

Table A3. (Continued).

County/LA	N Electoral wards	Arithmetic		Weighted		Max	Min	Median
		Mean	SE	Mean	SE			
Suffolk Coastal	8	15.8	10.2	15.5	3.9	27.8	4.3	16.3
Sunderland	21	14.8	7.8	16.4	2	32.1	5.7	13.3
Surrey Heath	13	38	8.8	42.4	3.2	55.7	26	36
Sutton	18	16.9	4	17.7	1.2	23.7	8	18
Swale	15	11.5	7.1	10	1.8	26.6	4.3	9.3
Swansea	28	18.8	8.4	19.6	1.5	45.1	6	18.2
Swindon	15	15.6	5.3	15.6	1.5	22.8	6.6	15.7
Tameside	17	18.9	6.6	19.2	1.6	30.9	6.7	19
Tamworth	10	14	3.8	13.8	1.2	18.6	8.4	14.7
Tandridge	10	31.3	9.5	33	4	49.3	19.3	28.9
Taunton Deane	14	10.8	3.3	10.8	0.9	17.5	6.3	10.6
Teignbridge	8	16.3	5.5	16.3	2.6	24.2	10.6	13.7
Telford and Wrekin	27	23.3	8.4	25.8	2.1	46.2	11.8	23.4
Tendring	22	7.6	4.5	8.2	1.5	18.6	1.3	7.5
Test Valley	9	19.3	14.6	19.8	6.5	47.3	5.5	20.2
Tewkesbury	13	11.9	4.5	13.3	1.7	22.7	6.4	11
Thanet	21	10.8	5.2	10.9	1.1	26.1	4.8	9.7
Three Rivers	11	27.9	9.9	28.1	2.8	51.4	18	24.3
Thurrock	14	12.1	6.5	10.4	2.1	21.9	2	11.2
Tonbridge and Malling	17	22.7	5.7	23.4	1.5	36	15.3	22.2
Torbay	14	15.6	5.7	17.1	1.5	23.8	6.2	15.9
Torfaen	20	21.4	7.7	21.8	2.4	36.8	4.9	20.5
Torridge	6	11.4	5.5	10.3	2.6	17.8	2.3	13.2
Tower Hamlets	20	14.2	3.6	14.9	1.4	25	5	14.3
Trafford	19	16.8	4.6	15.8	1.3	23.8	7.1	16.6
Tunbridge Wells	12	29.9	10.2	27.5	3.6	46.7	16.6	26.8
Uttlesford	5	14	5.8	14.3	2.6	22.1	7.3	14.3
Vale of Glamorgan	14	14.1	7.1	14.8	2	30.4	4	13.4
Vale of White Horse	8	19.3	6	19.5	3.7	30.2	9.6	18.7
Wakefield	7	17.3	1.7	17.3	0.6	20.3	14.9	17.2
Walsall	19	18.1	3	18.2	0.7	23.8	11.8	18
Waltham Forest	20	18.3	10.2	19.4	2.7	39.7	5.7	14.7
Wandsworth	20	17.7	6.8	19.9	2.1	38.7	9	16.3
Warrington	15	17.4	5.9	18.6	1.9	29.2	5.5	17.2
Warwick	16	14.4	4.8	15	1.6	28.2	9.3	12.6

(*Continued*)

Table A3. (Continued).

County/LA	N Electoral wards	Arithmetic		Weighted		Max	Min	Median
		Mean	SE	Mean	SE			
Watford	12	21.2	8	24.1	2.8	37.7	6.7	20.1
Waveney	14	14	4.9	14.5	1.5	26.6	7	12.7
Waverley	20	31.1	11.3	35.3	2.9	50	10.3	28.1
Wealden	16	22.9	10.3	20.1	3.5	43.3	7.2	21.8
Wellingborough	10	12	3.3	12.3	1.3	17.1	7	12.8
Welwyn Hatfield	10	21.7	7.8	23.2	2.9	39	11.7	20.6
West Berkshire	13	22.8	7.9	26.5	2.6	36.4	10.6	21
West Devon	3	17.8	2.6	16.8	1.9	19.8	14.9	18.8
West Dorset	9	12.3	4.3	12.5	2	21.1	6.6	11
West Dunbartonshire	2	14.9	2.7	14.4	1.9	16.8	13	14.9
West Lancashire	14	16.6	8.3	13.3	2.3	29.8	4.6	16.8
West Lindsey	3	14.2	3.2	14.8	2	16.8	10.7	15.1
West Oxfordshire	9	16.1	3.3	16.1	1.2	23.4	12.8	15.7
West Somerset	5	22.7	14.5	24.2	7.1	39.9	6	28.2
Westminster	20	15.8	6.9	18.1	2.4	28	5	13
Weymouth and Portland	15	7.7	4.2	6.6	1.3	15.4	1.7	6.3
Wigan	20	19.6	4.6	19.7	1.1	27.6	10.8	19.1
Wiltshire	50	15.1	5.2	14	1.1	25.8	2.2	15.3
Winchester	5	22	8.2	20	3.9	31.6	12.3	21.1
Windsor and Maidenhead	18	22.6	10.8	26.9	3.2	43.3	9.7	19.9
Wirral	16	12.7	5.3	13.9	1.4	22.2	4.6	12.4
Woking	8	26.2	6.3	27.3	2.5	36.3	19.1	24.2
Wokingham	19	26.2	8.7	27.2	2.3	55.2	16.4	23.8
Wolverhampton	20	15.4	3.6	15.6	0.9	23.2	10.4	14.4
Worcester	15	16.1	5.7	16.3	1.7	28.7	9.3	14.9
Worthing	13	16.2	7.1	18.3	2.7	34	7.9	14.3
Wrexham	37	18.8	7.4	22	1.5	32.2	4.9	18.3
Wychavon	11	13.3	3.3	13.3	1.2	20.3	9.8	11.7
Wycombe	18	24.1	6.6	26.1	1.7	36.3	12.3	23
Wyre	16	8.5	4	9.3	1.1	14.7	2.3	9.2
Wyre Forest	9	22	5.9	22.9	2.3	33.8	14.4	20.8
York	13	13.3	3.1	12.4	1.1	17	7.1	13.7