# A Comparison of Urban Tree Populations in Four UK Towns and Cities

## Abstract

Trees are a valuable asset to cities and towns, providing numerous services that sustain and support human life. They store carbon, filter airborne pollutants and intercept rainwater. The structure of urban tree populations and how resilient urban trees are to pests, diseases and changes in climate are relatively unknown. Surveys of urban trees using i-Tree Eco were conducted in Torbay, Wrexham, Glasgow and Edinburgh between 2010 and 2013 to assess the ecosystem services provided by urban tree populations. Data from these surveys can be used to analyse tree population structures and to make an assessment of the robustness of tree communities now and in the future.

There were similarities between tree populations in Wrexham and Edinburgh that may have been influenced by planting practices or similarities in land use types, rather than climate. Trees were most commonly encountered in parks and in residential areas. The populations of these land use types were also the most diverse. Each study area had at least two species that comprised more than 10% of the population, but no genus exceeded 20% and no family 30%. Torbay possessed the highest proportion of drought resistant species, whilst Glasgow, at risk from flooding, possessed very few waterlogging tolerant species.

If urban trees are to survive the future predicted changes in climate, consideration must be given to designing planting on a landscape-wide basis, taking into account species and site-specific properties.

## Introduction

In the UK, 80% of people live in cities, and the numbers are expected to increase (United Nations, 2009), with dense urban populations threatening to compound problems such as air pollution and warm urban microclimates. Finding novel solutions to help reduce such impacts will become ever more important as governments strive to keep cities habitable. Ecosystem services are services provided by nature that have positive impacts on humans and, in many cases, allow humans to exist (Daily, 1997). An example would be the oxygen required to breathe, which is produced naturally by plants. Urban tree populations, referred to as 'urban forests' (Nowak *et al.*, 2010), offer a range of ecosystem services, such as carbon capture, atmospheric pollution removal and local climate regulation. The urban forest therefore has the potential to mitigate many urbanisation impacts.

Several methods have been devised to assess the ecosystem service benefits of urban trees, including i-Tree Eco, hereafter referred to as i-Tree. i-Tree, developed by the United States Forest Service, has been assessed to be one of the most robust tools for assessing the ecosystem services provided by trees (Sarajevs, 2011). i-Tree provides a standardised method for surveying urban trees, making comparisons between study areas informative, and has the potential to be applied across the UK.

Four i-Tree studies have been conducted in the UK by the authors: in Torbay (Rogers *et al.*, 2011a), Wrexham (Rumble *et al.*, unpublished a), Glasgow (Rumble et al. unpublished b) and Edinburgh (Hutchings *et al.*, 2012) between 2010 and 2013. These studies have shown trees to be an important asset in urban areas, providing a range of ecosystem services.

**Keywords:**

diversity,
i-Tree,
species composition,
urban forest inventory

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The aim of this paper is to further the initial i-Tree analyses to determine whether the urban forests surveyed will continue to deliver ecosystem services in the future by being resilient to change. An i-Tree survey offers a 'snapshot in time' assessment of ecosystem services provision. The types of analyses demonstrated in this study extend this snapshot, enabling tree officers and local councils to plan for the future and to understand where gaps in knowledge exist.

Three aspects were studied to achieve this aim. The first was the structure of the urban forest in terms of species distribution and age, and how these factors vary with land use type. Previous research suggests that species composition varies, with different dominant species across the UK (Brus *et al.*, 2011). This is particularly pronounced when comparing southern areas (such as Torbay) with northern ones (such as Glasgow and Edinburgh). As such, we hypothesise that differences in species composition differ most between Torbay and the Scottish cities. Analysing the age distribution of urban forests will also enable tree officers to plan for the long term by aiding predictions about trees' longevity.

The second factor studied was the diversity of the urban forest. Diverse ecosystems tend to be more resilient to change than monocultures, with many pests and diseases targeting specific species or groups of species (Johnston *et al.*, 2011). Thus, the more species present, the less the impact from this threat.

Thirdly, the species-specific properties of the urban forest in relation to the abiotic factors of drought and waterlogging were examined. UK climate predictions suggest warmer, drier summers and wetter winters within the next 50 years, increasing the risks of unprecedented drought and flooding in certain areas (UKCP09, 2009). Considering that the life of a tree may span 150 years or more, it is essential to determine whether current tree stocks are resilient to these changes and how urban planting practices can be improved in this regard.

## Methods

i-Tree surveys were carried out in Torbay (2010), Edinburgh (2011), Glasgow (2013) and Wrexham (2013). All four surveys were carried out in accordance with the i-Tree Eco manual (Torbay: version 3.1 (i-Tree 2010); Edinburgh: version 4 (i-Tree, 2011); Glasgow and Wrexham: version 5 (i-Tree, 2013)), with the following differences in field collection. Different numbers of plots and plot densities were used in each study area (Table 1), although all used randomised grids to select the plot locations. Torbay used a different diameter at breast height (DBH) threshold to define a tree, including any tree above 2.54 cm in diameter. For all of the other surveys, 7 cm was used, therefore trees below this threshold DBH were filtered from the Torbay dataset. Dead trees were not recorded in Edinburgh, so these too were filtered from the other datasets.

**Table 1:** Differences in plot number and number of hectares represented by each plot

| Study area | No. plots | Plots/Ha |
|---|---|---|
| Wrexham | 202 | 19 |
| Torbay | 241 | 26 |
| Edinburgh | 200 | 57 |
| Glasgow | 200 | 88 |

The differences between urban forest community structures were explored by performing principal components analysis (PCA) on individual trees identified to species level only. Tree frequencies were expressed as trees sampled per hectare. PCA was performed in R (R Core Team, 2013) using the package FactoMineR (Husson et al., 2009).

An index of tree species by stature height was devised and used as a grouping structure to aid further analysis. The index was based on several literature sources (GLA, n.d.; Barcham Trees, 2012; Royal Horticultural Society, 2011). Small stature trees were defined as reaching a maximum height of 10 m, whilst anything larger was deemed a large stature tree. Sampled trees were then assigned DBH size classes based on those in Richards (1983) (<20 cm, 20-40 cm, 40-60 cm and 60+ cm).

The majority of the trees were identified to species level, but where this was not possible the genus alone was recorded. To account for such instances, the total numbers of species found in each study area are expressed as 'more than' the number of species identified to species level to include trees identified to genus level only. Species frequencies were compared to guidelines taken from Santamour (1990), who recommends that no one species should exceed 10% frequency in a tree population, no genus 20% and no family 30% within a given area. Diversity was calculated using the Shannon Wiener index, which takes into account the number of different species and their frequency within a population. This was calculated using only the individuals that were identified to species level.

Tree sizes and diversity indices were divided by land use type. Land use types were defined as outlined in the i-Tree methodology (i-Tree, 2013). Residential areas means those populated by freestanding residences serving one to four families each. Multi-family residential areas were those populated by structures serving more than four families. Agricultural land referred to any land managed for a specific crop, including orchards and allotments. Parks included maintained and unmaintained parks. Vacant land was land with no clear intended purpose. 'Other' was used rarely, but encompassed land uses not outlined by the i-Tree methodology.

Drought tolerance was assessed for all of the species encountered in the study areas using the approach of Niinemets and Vallardes (2006). Additional information for species not included in this index was retrieved from Gilman and Watson (1994); Royal Horticultural Society (2011); Greater London Authority (n.d.) and United States Department of Agriculture (n.d.). Waterlogging tolerance was assessed for Glasgow only, as a case study, as the city has experienced several major flooding events in recent years, particularly in the White Cart Water area (Glasgow City Council, n.d.). Species within flood risk areas were assessed according to the waterlogging tolerance rankings of Niinemets and Vallardes (2006). Flood risk areas for were obtained from the Scottish Environment Protection Agency (SEPA) using 100-year events (SEPA, 2014). Plots that fell partially or entirely within these areas were assessed as being within flood risk areas.

# Results

## Species Composition and Urban Forest Structure

Only two species, *Fraxinus excelsior* and *Acer pseudoplatanus,* were in the top ten species in all four study areas. *Betula pendula, Crataegus monogyna* and *x Cupressocyparis leylandii* were found in the top ten abundances in three of the study areas. The frequency distribution of species in the top ten abundances was similar for all four study areas (Figure 1).

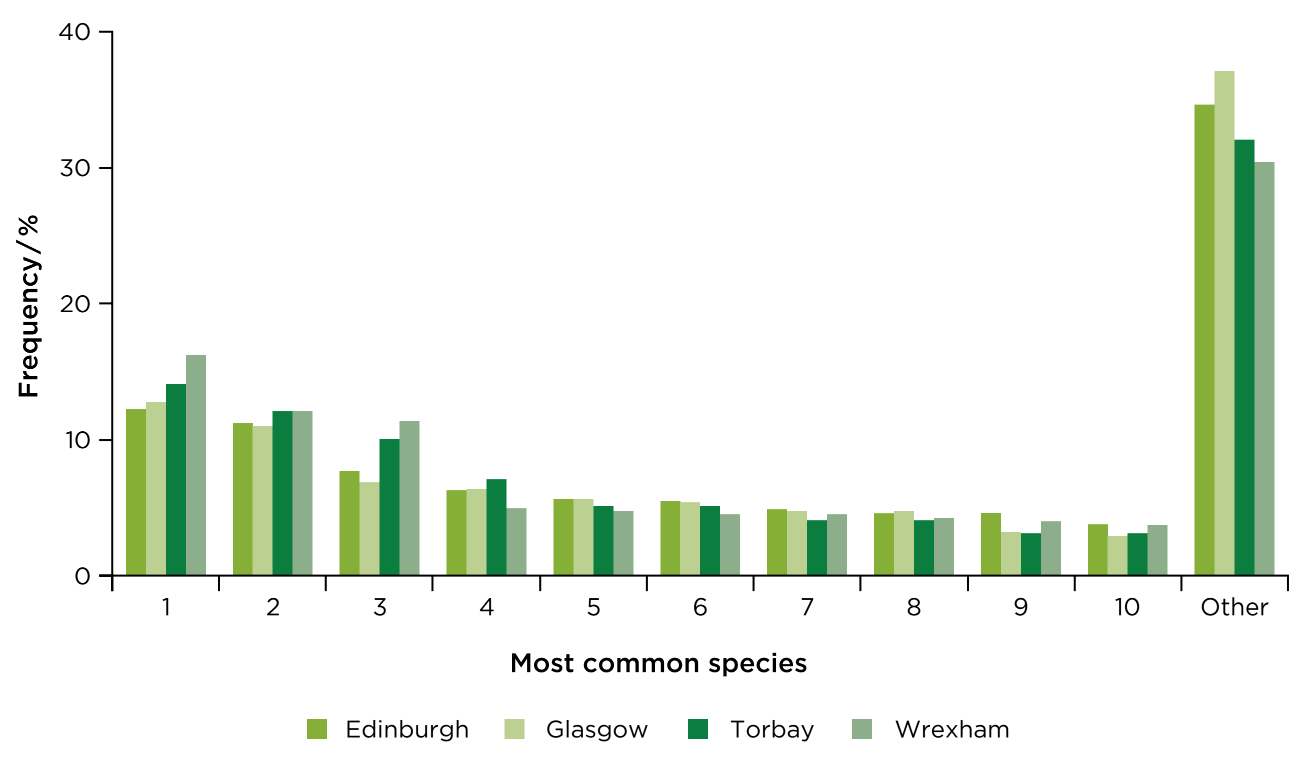

**Figure 1:** Frequency (%) of the ten most common species in the four study areas, with other ranks grouped

The PCA suggested that the species compositions in Wrexham and Edinburgh were more similar to one another than to the other two sites (Figure 2).

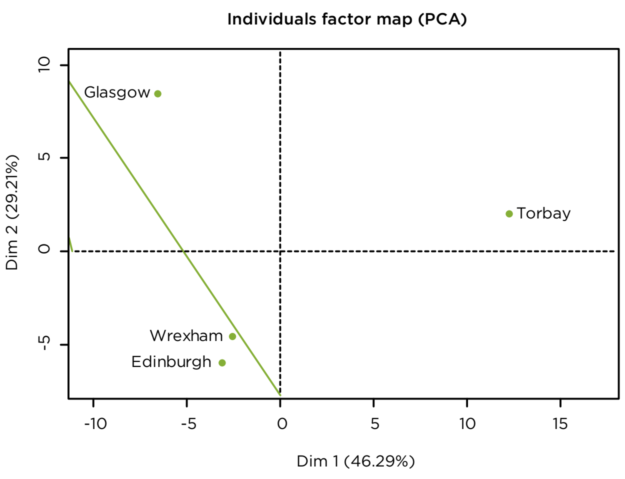

**Figure 2:** PCA ordination plot depicting the species composition for each study area. Trees identified to genus level only were omitted from the analysis. Frequencies were expressed as trees per hectare

In plots where trees were present, parks and residential areas had the highest frequencies in all four study areas (Figure 3).

For large stature trees, all four sites shared similar species size distributions, with a high proportion of small trees compared with large trees in the plots. The Glasgow plots had the lowest proportion of trees with diameters between 40 and 60 cm, whilst both Scottish cities contained the highest proportions of large diameter trees. The Glasgow plots also had the highest proportion of small diameter trees. All of the study areas had proportionally too many small trees compared with other sizes when using the distributions recommended by Richards (1983). All four study areas followed a downward trend with regards to tree size (Figure 4).

The Edinburgh plots had the highest percentage of small stature trees (35%), with all other sites ranging between 20-30%. Residential properties contained more large stature trees than small stature trees ($\bar{\chi}$ = 40%, ± 13%). The study areas mainly differed in the proportion of small stature trees in different land use types, excluding golf courses, utility areas and wetlands, where only one land use type or fewer contained small stature trees so could not be compared. Parks, however, varied little in their ratio of small to large stature trees, with the proportion of small stature trees varying by only 3% across the survey sites ($\bar{\chi}$ = 25%, ± 1.5% for small stature trees) (Figure 5).

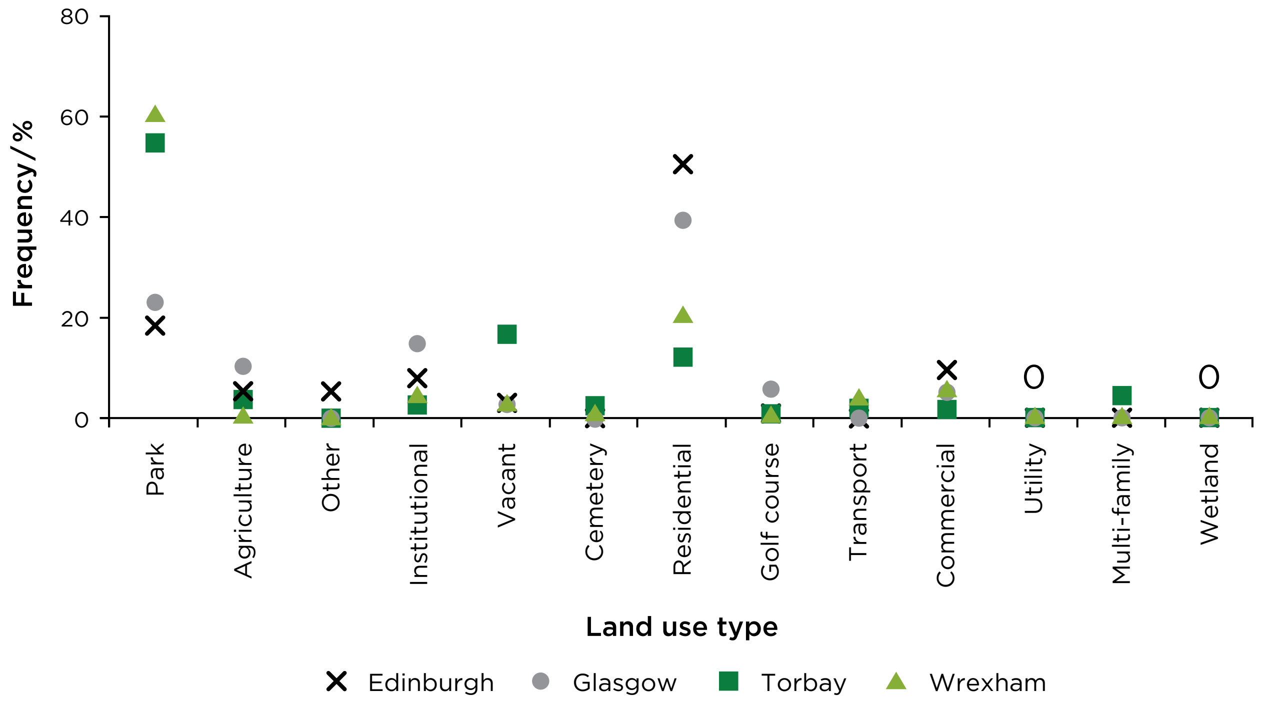

**Figure 3:** Frequency of trees in each land use type where trees were present. The number 0 denotes land use types where no trees were found

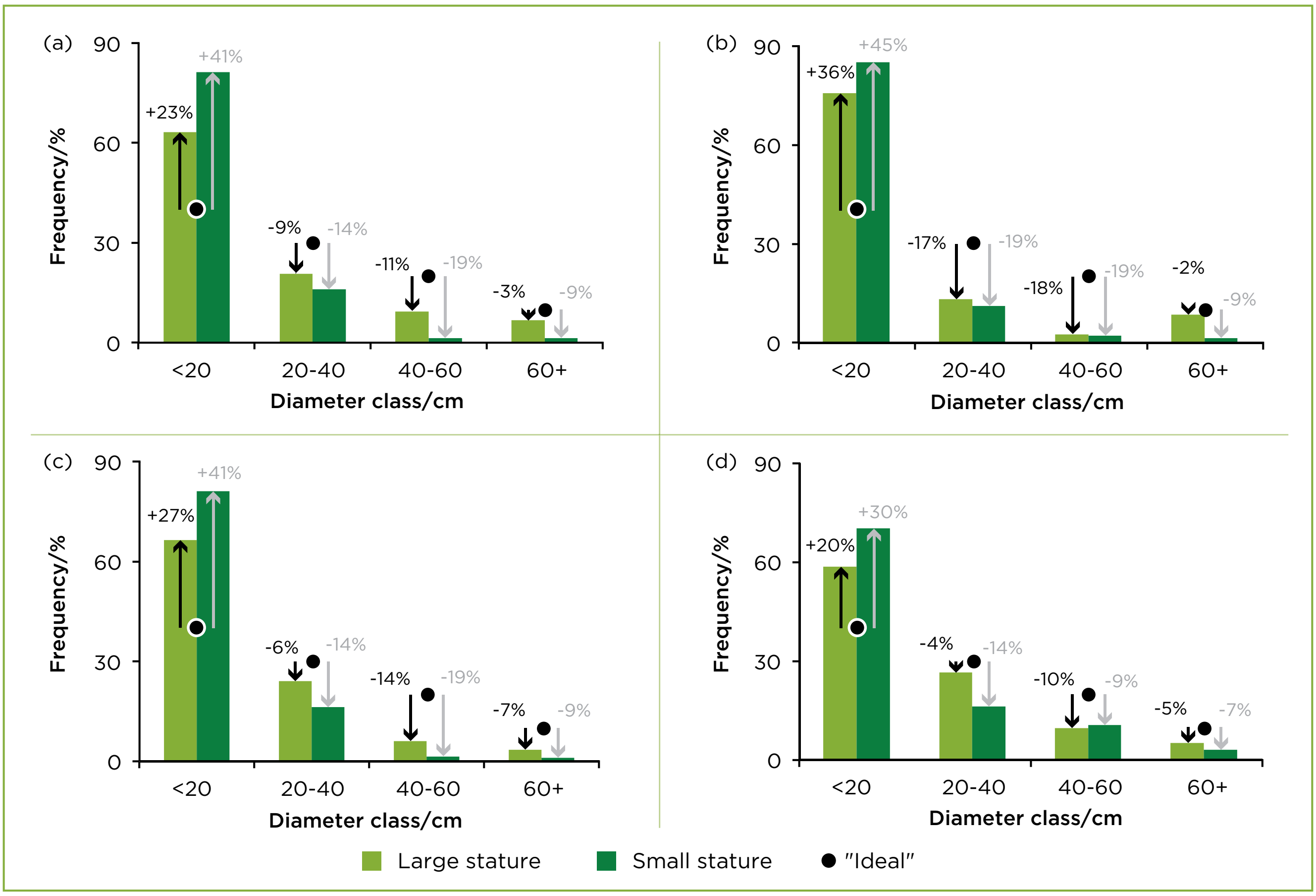

**Figure 4:** Frequency within diameter ranges in (a) Edinburgh, (b) Glasgow, (c) Torbay and (d) Wrexham. Dots represent 'ideal' values as suggested by Richards (1983), with data labels representing the differences between the actual samples and this 'ideal' value. Arrows denote the direction of difference between the actual and 'ideal' values. Small stature values are expressed for illustration

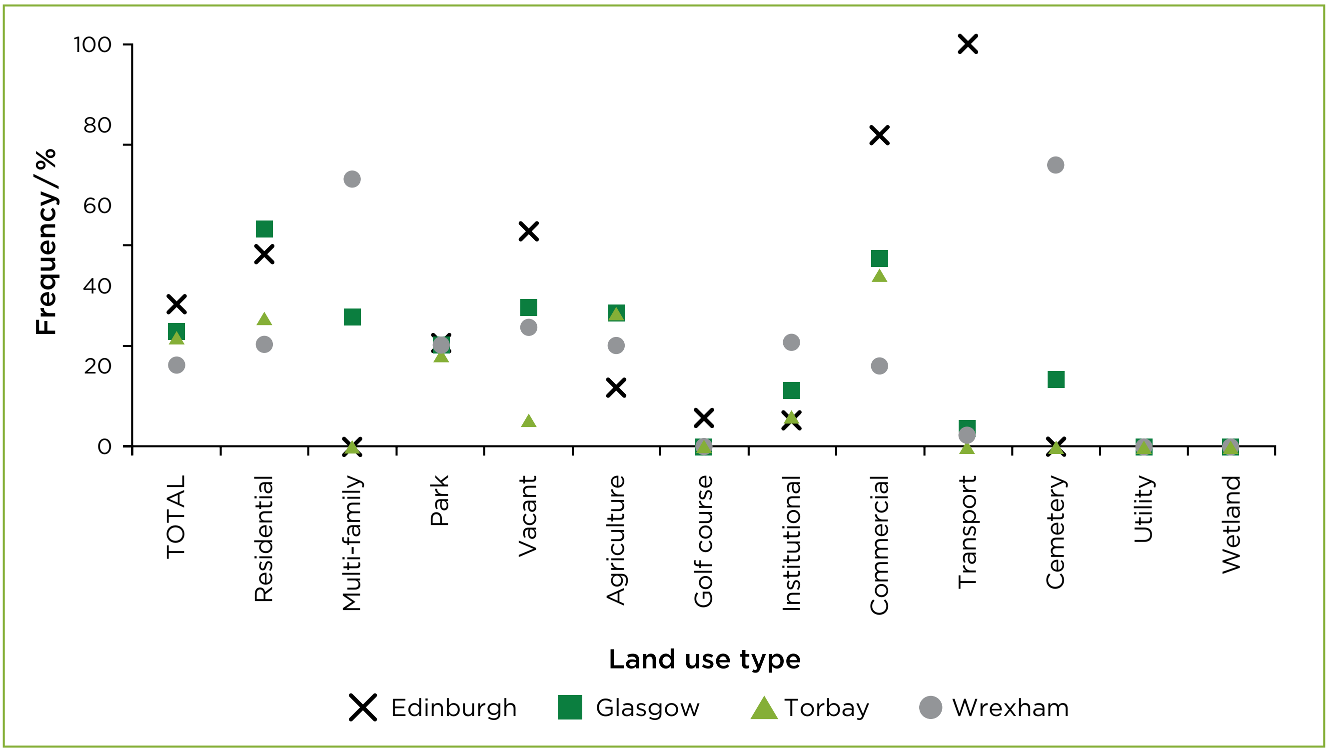

**Figure 5:** Frequency (%) of small stature trees in the four study areas. The number 0 denotes land use types where no trees were found

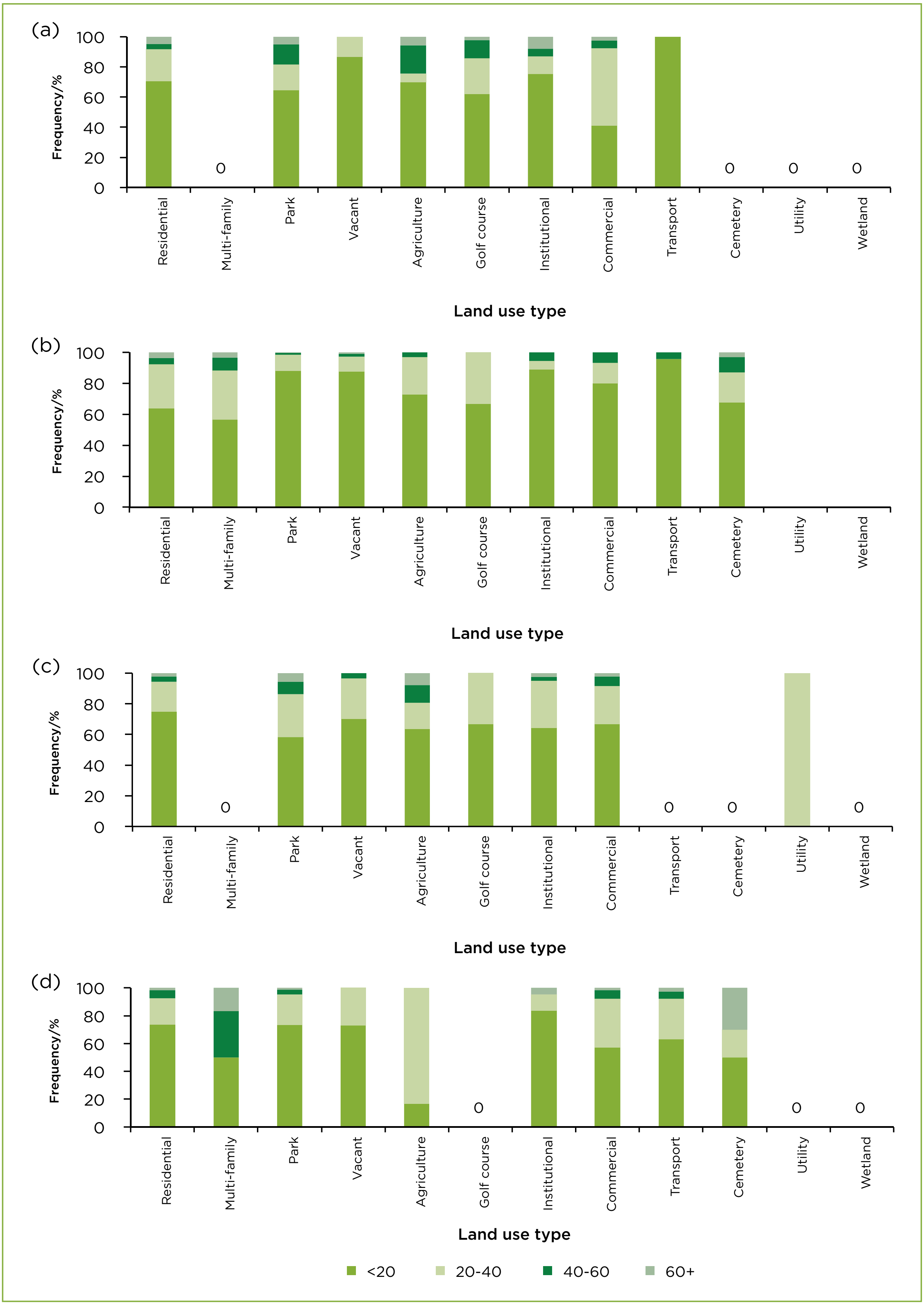

**Figure 6:** Proportion of diameter size classes per land use type for (a) Edinburgh, (b) Glasgow, (c) Torbay and (d) Wrexham. The number 0 denotes land use types where no trees were found

Analysing all tree statures, the relative proportion of 60 cm+ sized trees in the plots varied. In Glasgow and Edinburgh, where the highest percentages of trees in this size class were found, large trees were spread across several land classes. In Edinburgh, proportionally more 60 cm+ trees were encountered on institutional land than any other land use type (8%), although residential areas (5%), parks (5%) and agricultural land (6%) all had high (<3%) proportions. In Glasgow, residential areas (4%) were the only areas to contain proportionally more than 3% of 60 cm+ trees. In Wrexham, 60 cm+ trees were in high proportions in cemeteries (30%), on sites where multi-family residential properties were situated (17%) and on institutional land (5%). Parks (6%) and agricultural land (8%) harboured high proportions of 60 cm+ trees in the Torbay plots (Figure 6).

## Diversity

All four study areas contained at least two single species that exceeded a frequency of 10% (Table 2). Wrexham had the most species in this category (three species, totalling 42%), whilst Edinburgh had the fewest (two species, totalling 23%). No area exceeded either the genus limit of 20% or the family limit of 30%.

Diversity as measured using the Shannon Wiener diversity index varied little between the four study areas. The Wrexham plots marginally supported the least diversity and Glasgow the most (Figure 7). Residential sites and parks had the highest Shannon Wiener diversity in all of the surveyed study areas. Where trees were present, golf courses, institutional land, commercial land, land associated with transport and cemeteries all showed similar patterns of diversity. Of these, institutional land and commercial land were the most diverse, and golf courses and cemeteries the least. Areas containing multi-family dwellings varied in Shannon Wiener diversity, with Glasgow possessing a higher diversity of trees compared with Wrexham. Edinburgh and Torbay had no trees surveyed on this land use type. On vacant land, the Shannon Wiener diversity was higher in Glasgow than in the other areas. On agricultural land, Torbay and Edinburgh had a high Shannon Wiener diversity compared with Glasgow and Wrexham. Agricultural land was one of Torbay's most diverse land use types (Figure 7 (over)).

**Table 2:** Number of species, genera and families in each study area and tree species exceeding the frequency limits set out by Santamour (1990)

| Study area | No. species | Species exceeding 10% | No. genera | Genera exceeding 20% | No. families | Families exceeding 30% |
|---|---|---|---|---|---|---|
| Torbay | >94 | x Cupressocyparis leylandii (16%)<br>Fraxinus excelsior (13%) | 62 | 0 | 33 | 0 |
| Wrexham | >53 | Acer pseudoplatanus (17%)<br>Crataegus monogyna (13%)<br>Betula pendula (12%) | 32 | 0 | 17 | 0 |
| Glasgow | >65 | Fraxinus excelsior (13%)<br>Crataegus monogyna (11%) | 33 | 0 | 19 | 0 |
| Edinburgh | >49 | Acer pseudoplatanus (12%)<br>Ilex aquifolium (11%) | 27 | 0 | 16 | 0 |

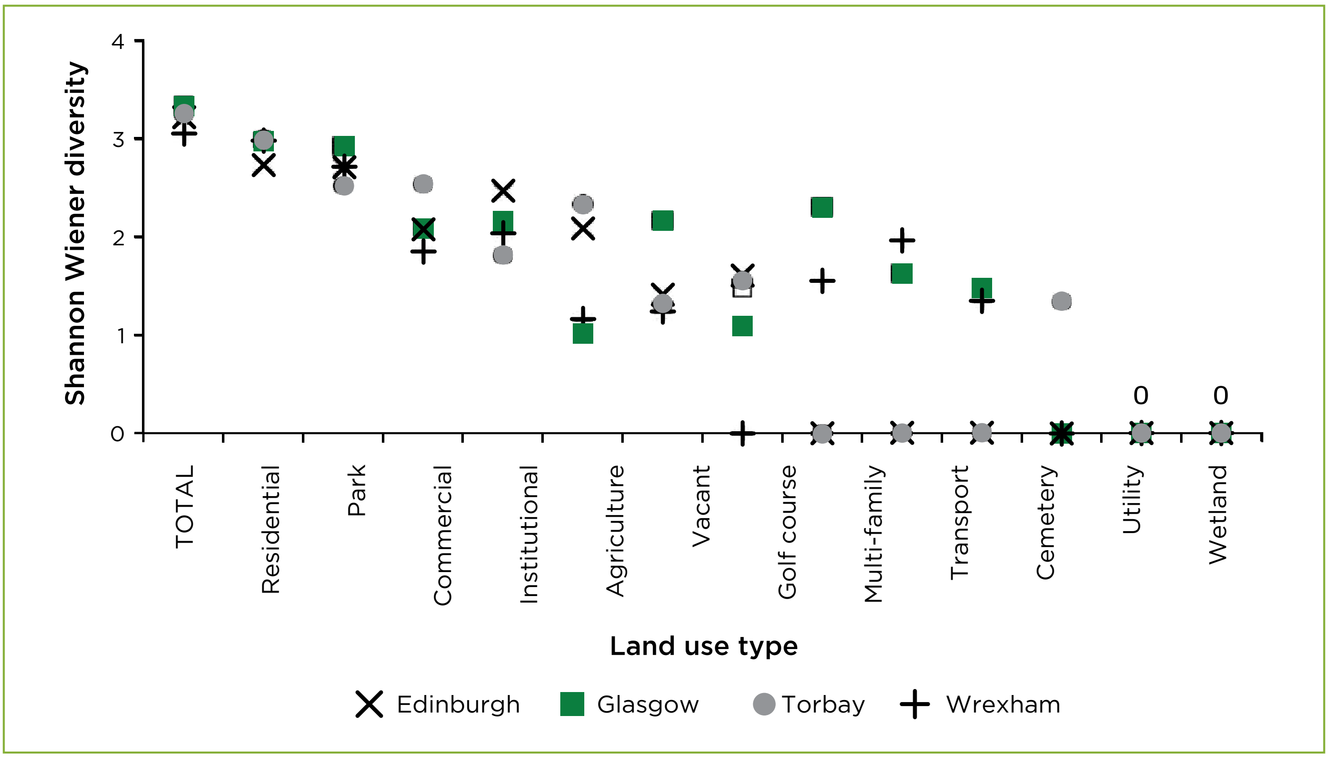

**Figure 7:** Shannon Wiener diversity for each study area and land use type. The number 0 denotes land use types where all of the study areas received a Shannon Wiener index of 0

## Response to Drought

An assessment of the drought tolerance of the urban trees surveyed was conducted based on the index developed by Niinemets and Vallardes (2006), scaled 1 for the lowest drought tolerance and 5 for the highest drought tolerance. In the more northerly areas of Wrexham, Glasgow and Edinburgh, the highest frequency of trees (for which an index was available) belonged to species with a drought tolerance of between 1.9 and 3 (Niinemets and Vallardes, 2006) (Figure 8). Torbay, however, contained proportionally more drought tolerant species, with more trees with indices between 2.9 and 5 (Niinemets and Vallardes, 2006) (Figure 8).

**Figure 8:** Drought tolerance of all species (for which an index was available) in all of the study areas according to Niinemets and Vallardes (2006). The number 0 denotes index ranges with a tree frequency of 0%

All four study areas contained trees that were either not listed in Niinemets and Vallardes (2006) or that had been identified to genus level only in the field so could not be assigned a drought index value. Torbay contained a high proportion of trees not listed in Niinemets and Vallardes (2006), and very few were identified to only genus level. The unlisted species included *Laurus nobilis, Pittosporum tenuifolium, Ulmus procera, C. leylandii* and *Cordyline australis*, of which all except for the last are highly drought tolerant. The other three study areas contained few, if any, unlisted species, suggesting a higher prevalence of drought tolerant species in Torbay than in the other three study areas.

### Response to Waterlogging – Glasgow as a Case Study

Eight percent of the Glasgow study area is included in the SEPA's 100-year flood-risk area (SEPA, 2014). Eighteen of the sampled plots fell wholly or partially within this area, with six of these containing trees. Ninety-seven trees in total were sampled in the 100-year flood risk areas. Nearly half the total trees in those areas (48%) were species not tolerant of waterlogging (Niinemets and Vallardes, 2006), whilst only 4% were species highly tolerant of waterlogging (Figure 9).

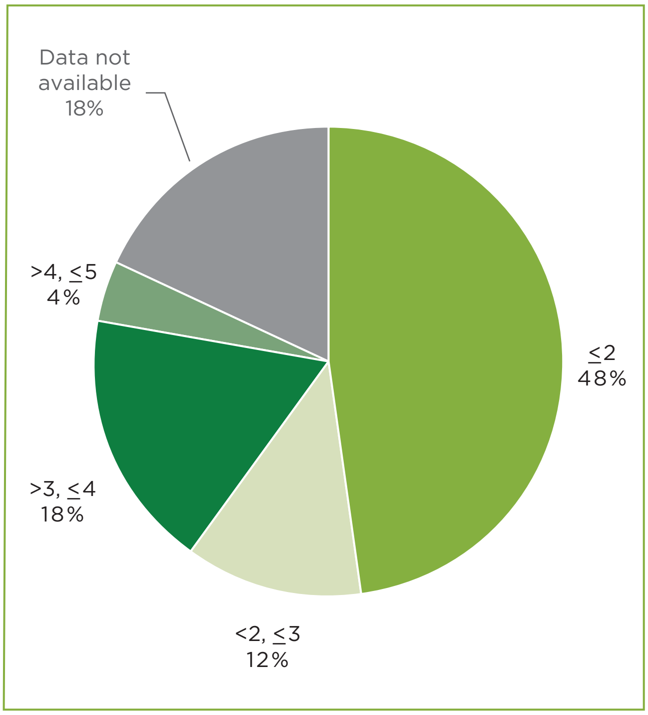

**Figure 9:** Proportion of trees in flood risk areas in Glasgow tolerant of waterlogging (Niinemets and Vallardes, 2006), where 1 is the lowest and 5 the highest

## Discussion

### Species Composition and Urban Forest Structure

The prevalence of *A. pseudoplatanus* and *F. excelsior* as a species in the top ten most abundant trees sampled suggests that the findings of Britt and Johnston (2008), who studied English urban areas only, may also be representative of a greater proportion of the UK. *C. monogyna, C. leylandii* and *B. pendula* all feature in the top six trees recorded in Britt and Johnston (2008), and these too were prevalent in the plots across the study areas.

Species composition in the Torbay plots differed from that in the other three study areas, confirming the pattern of species distribution outlined in Brus *et al.*, (2011) and supporting our hypothesis that species composition in the southern areas would differ from that in the northerly areas. Wrexham and Edinburgh were the most similar in terms of species composition, suggesting that climate is not necessarily the driving factor. Both of these study areas contained a high ratio of broadleaves to conifers, and both were dominated by *A. pseudoplatanus*, with similar species frequencies for *F. excelsior* and *B. pendula* (Hutchings *et al.*, 2012; Rumble *et al.*, unpublished a). These three species are likely to be driving the PCA patterns due to their abundance. As all three species are pioneer species (Willoughby *et al*. 2004; Forestry Commission n.d.) that are proficient at self-seeding, their prevalence suggests that land use is driving the major differences in species composition. Although there were no obvious similarities in land use types between Wrexham and Edinburgh that could explain the similarity in species assemblage, the resolution of the land use type data collected in i-Tree may not be sufficient to have identified this correlation. Parks made up a high proportion of the land use in all four study areas, but a 'park' in terms of an i-Tree survey can be either a maintained park or a wild park. The species compositions of these two land-use types are likely to differ, with more self-seeding colonisers in wild parks.

Determining whether trees have been planted or are self-colonised is also useful in terms of understanding tree size ranges. Glasgow, for example, had a high proportion of small trees capable of attaining a large stature. This could be due to recent planting efforts or to land use change that allowed self-colonising species to enter a habitat. If the latter, it would be expected that Wrexham would show a similar pattern. Both Glasgow and Wrexham have undergone significant land use change compared with Edinburgh and Torbay in the past 50 years due to the decline of industry (Walsh *et al*., 2008; Simpson, pers. comm.), resulting in an increase in vacant land that trees can colonise. Wrexham, however, had the lowest proportion of small trees capable of attaining large stature, suggesting that planting practices are the more likely driver.

Further analysis of maintained and wild land use types using aerial photography, post-survey, could clarify whether the species compositions of maintained and wild parks differ, but it is also recommended that for future i-Tree surveys a distinction be made between these two land use types. This would enable researchers to determine how land use and planting practices affect tree assemblages. Combining this with data on niche availability would determine what drives tree communities in different land uses.

All four study areas showed broadly similar size distribution patterns for large stature trees, with many small trees and a downward trend in the frequency of trees of 20 cm upwards. The large proportions of small trees (<20 cm) suggests a recent peak in planting that exceeds the guidelines suggested by Richards (1983) to ensure that tree losses at later stages are accounted for. The subsequent downward trend in the proportion of trees of 20 cm upwards suggests continuous planting over time, with natural tree mortality reducing large tree populations, and continuous planting or natural recruitment replacing these lost trees (Richards, 1983). Using mensuration data to glean a better understanding of the relatively few 40-60 cm trees in Glasgow provides no significant additional clarity. For the 10 species encountered in Glasgow within the 40-60 cm size class, mensuration data suggests an age range of 50 to 150 years, which is too large to relate to a specific event. In addition, data is sparse for non-crop species such as *Tilia x europaea,* and forest stand trees have different growth patterns to urban trees (McHale *et al*., 2009). Hence, there is a pressing need for growth rate studies of urban trees if data such as that reported here is to be better interpreted.

Comparisons between the i-Tree results and the 'ideal' species size distributions as outlined by Richards (1983) have been used in previous i-Tree surveys (Rogers *et al*., 2011a; Toronto Parks, Forests and Recreation, n.d.). However, these guidelines are based on street trees, highlighting a need for more research into their applicability across other land use types. Street trees were relatively rare in all four i-Tree surveys, and the natural processes of recruitment and death probably vary across different land uses, tree species and management practices. Taking these variables into account, research into the maximum sizes that urban trees may attain within their lifetime, in addition to mortality and recruitment effects in different land use types, would enable tree officers to 'design' young forests to produce the desired mature forests. This would also mean that biases introduced by small and large stature trees could be overcome. Small stature trees comprised 20-40% of the urban forest populations surveyed, a portion of the forest that will never contribute to the largest sizes of tree and so should not be included in the Richards (1983) guidelines. Treating small stature trees as a separate population allows more useful predictions of future forest structure to be made.

The abundance of large trees (60 cm+) on different land use types varied across study areas. Often, 60 cm+ trees were found on land use types that commonly go through little land use change over time, such as cemeteries and parks, but many other land use types contained high proportions of large trees. This was particularly true in Glasgow and Edinburgh, where large trees were less aggregated by land use type than in Torbay and Wrexham.

The motivation for planting species capable of attaining a large stature is to maximise ecosystem service delivery. Per tree, large stature trees provide more ecosystem services, perhaps up to four times the net value in annual ecosystem services provided by small stature trees (USDA, n.d). Hence, ensuring that populations of large stature trees are maintained or improved will have benefits to society in the future. Even once small stature trees were removed from the analysis, all four study areas possessed fewer than the 10% target of 60 cm+ trees outlined by Richards (1983) for street trees. It can be argued that although these guidelines are for street trees, these are the most expensive trees to plant within the land use types surveyed, and that overall urban tree communities should, therefore, be able to exceed the recommended numbers of larger stature trees.

## Diversity

All four study areas had at least two species that comprised more than 10% of the population, greater than the 10:20:30 guideline for species, genus and family (Santamour, 1990). Wrexham had the highest proportion of dominant species, with three species comprising 42% of the population. However, at present, the three species that dominated (*A. pseudoplatanus, C. monogyna, B. pendula*) are not at immediate threat from pests or diseases (Forest Research, 2014). Santamour (1990) notes that this guideline was devised to protect against an unknown pathogen or pest, which is wise considering the longevity of a species such as *A. pseudoplatanus*, which exceeded the 10% rule in two of the study areas and may live for over 300 years (Royal Botanical Gardens, Kew, n.d.). Both *A. pseudoplatanus* and *B. pendula* could, however, succumb to Asian longhorn beetle were it to establish in the UK (Forest Research, 2014).

No species in any of the study areas exceeded either the 20% limit for genus or the 30% limit for family. The extent to which urban tree populations in general break these limits therefore calls into question the applicability of this guideline, which may need revisiting. Although a simple rule of thumb for tree officers, this rule could be refined using data from recent outbreaks elsewhere, such as gypsy moth (*Lymantria dispar dispar)* in the United States. Applying the 10:20:30 rule to forests within the gypsy moth's invasive range to determine whether those populations breaking the rule have suffered more damage than those adhering to it would provide an indication as to the robustness of this rule. Another aspect to consider is that tree officers applying this rule have, in reality, inventories only for council-owned land and private trees with Tree Preservation Orders (Simpson, pers. comm.; Zipperer *et al*., 1997). In the current study, council-owned land (parks, roadsides, cemeteries and institutional land) made up 25% to 70% of the land use types, suggesting that if records within councils only cover these types of land use, up to 75% of trees in an urban area may be missing from inventories. Again, this emphasises the value of conducting multi-area tree surveys, such as those provided by i-Tree, before drawing conclusions about the susceptibility of urban forests to pests and diseases.

The Torbay survey recorded the highest number of species of all four surveys. Many of these species were exotic trees (Rogers *et al*., 2011b), which are commonly planted in residential properties. However, Torbay did not have the highest diversity index. This is because the Shannon Wiener diversity index accounts not only for species richness, but also for species abundance to indicate whether certain species dominate an assemblage. The top ten most frequent trees in the Torbay plots equalled 67% of the total species present, 4% higher than the figure for Glasgow, the study area with the highest diversity index. In general, the diversity varied little between the four study areas.

The diversity across land use types was highest in the residential and park plots; unsurprising given that these are maintained landscapes that include exotics. These areas may therefore be more resilient to invasions of pests and diseases than other land use types, such as agricultural land, golf courses and cemeteries, where the lowest diversity indices were reported. However, although more resilient to pests and diseases, large numbers of exotics also tend to support less wildlife (Kennedy and Southwood, 1984).

## Response to Drought

Drought tolerance indices were higher in Torbay than in the northern study areas, and a high proportion of species not included in the Niinemets and Vallardes (2006) drought tolerance index were also drought tolerant. Climate change projections indicate that the mean summer temperatures in all four regions will increase by at least 1°C by the 2050s, with middle probability estimates indicating an increase of at least 2°C (UKCP09, 2009). Summer rainfall is also predicted to decrease by at least 13% (UKCP09, 2009) (Table 3). The south-west of England, where Torbay is located, is projected to have the highest temperature increases and the largest decrease in summer rainfall. The prevalence of drought tolerant species in these areas may enable Torbay's urban forest to withstand the impacts of a changing climate. However, little work has been done to determine how much of a temperature rise specific species could cope with. Broadmeadow and Samuel (2005) analysed the productivity of broadleaves under different climate and atmospheric change scenarios across the UK, and found that initially, many species might benefit from increased levels of $CO_2$, but that extreme changes in weather would eventually decrease their productivity. Ray and Petr (2009) modelled the impact of climate change on *Picea sitchensis* in the UK, taking a specific water deficit as

Table 3: Climate change scenarios for each of the study areas based on projections into the 2050s under medium emissions scenarios (UKCP09, 2009). All figures given are central estimates of change compared with the 1961-1990 baseline, with confidence intervals in brackets (lower bound 10%, upper bound 90%)

| Study area | Mean summer temperature/°C | Mean winter temperature/°C | Mean summer precipitation/% | Mean winter precipitation/% |
|---|---|---|---|---|
| Torbay (South-West) | +2.7 (+1.1, +5.1) | +2.1 (+0.8, +3.5) | -20 (-45, +16) | +17 (0, +41) |
| Wrexham (Wales) | +2.5 (+1, +4.6) | +2 (+0.8, +3.4) | -17 (-38, +13) | +14 (-1, +31) |
| Glasgow (Scotland West) | +2.4 (+1, +4.4) | +2 (+0.8, +3.3) | -13 (-28, +6) | +15 (-1, +31) |
| Edinburgh (Scotland East) | +2.3 (+1, +4.5) | +1.7 (+0.6, +3.1) | -13 (-28, +6) | +10 (-2, +20) |

a case study (180 mm). They mapped areas where this level of rainfall was likely to occur under climate change, and determined how many trees would die as a result. Similar studies with common urban trees could enable tree officers to plan better for climate change. Proxies using countries with current climates similar to projected UK climates would also help to determine the effects of climate change, emphasising the usefulness of the uptake of i-Tree in different cities around the world as a standardised method. Mean temperatures in Torbay are already 1-2°C warmer than in the other three study areas (Met Office, 2010), so could be used as a proxy by Wrexham, Glasgow and Edinburgh.

### Response to Waterlogging – Glasgow as a Case Study

Few species within current flood areas were highly tolerant of waterlogging, with half of the species obtaining indices of less than 2. Niinemets and Vallardes (2006) note that as most species in the Northern hemisphere are not tolerant of waterlogging according to their index, the index may need recalibrating, and thus may not be useful at low ices. However, very few tree species found in the Glasgow flood areas scored highly on the index either, suggesting a lack of waterlogging tolerant species where they are needed. UKCP09 (2009) projects a 10-17% increase in winter precipitation in the 2050s, potentially increasing the flood intensity in some areas of the UK (Kay *et al.*, 2006), and urban planting schemes should reflect this likely trend.

The data emphasise the challenges that climate change poses to tree planting schemes, with a need to plant both drought and waterlogging tolerant species. However, there are two areas of research that would help inform site-specific tree planting further. The first is research into specific tree tolerances to extremes, for example, how long a tree can be waterlogged before there are negative health implications or how little water tree species can survive with and for how long.

Niinemets and Vallardes (2006) found that species that were highly drought tolerant were rarely waterlogging tolerant and vice versa, yet climate predictions suggest that both drought and waterlogging will be an issue in the next 50 years. Consequently, research should extend to testing combinations of stresses. The second improvement is the provision of detailed maps of flood and drought risk areas that include how prolonged drought or flooding might be, although the latter in particular is a significant challenge. Both of these improvements would allow local tree officers to plant species suited to local conditions not only now, but in the future.

## Conclusions

i-Tree surveys highlight how important trees are for ecosystem services, but without long-term monitoring and quality research into species-specific resilience to change, the value of trees in the future is unpredictable. Diversity varied little among the four study areas, and tended to be highest in maintained areas. However, without guidelines on the level of diversity required to produce an urban forest that is resilient to pests and diseases, it is not possible to recommend what alterations should be made. Drought tolerant species were more prevalent in the southern study area than in the rest of the UK, and could be used as an example to inform planting to future-proof northern cities against climate change. However, Torbay may need to draw comparisons with countries elsewhere in Europe to determine how resilient its own urban forest will be to climate change. Using Glasgow as an example, waterlogging stress may be a significant challenge to urban forests in the future, as current tree stocks contain few species that are tolerant of this problem.

The threats to urban forests due to climate change are likely to increase in the near future (Read *et al*., 2009) and due to the slow growing nature of trees, need to be addressed soon. Surveys such as i-Tree are broad, fast and inexpensive and produce useful, standardised results. Additional research into species-specific factors, such as drought tolerance, could supplement i-Tree results, making them more useful for predicting future urban forest composition. Moving forward, a combination of data collection in the field and *in vitro* experimentation would enable researchers and tree officers to ensure that the valuable urban forests that populate our cities and towns continue to deliver in the future.

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