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RESEARCH PAPER

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A global comparison of the climatic niches of urban and native tree populations

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Abstract

Aim: Urban macroecology studies can provide important insights into the impacts of climate change and human intervention in ecosystems. Current theory predicts that urban trees are constrained by temperature in very cold climates but not in other climates. Here we predict the climatic niche variables of planted urban tree populations from the realized climatic niche of native populations and explore whether niches are constrained across all temperatures.

Location: Global (182 cities across six continents).

Time period: Urban tree data: 1980–2016. Native tree data: 1950–2017.

Major taxa studied: Two hundred and three tree species.

Methods: We used urban tree inventory data and Global Biodiversity Information Facility occurrence data to compare the realized climatic niches of native and urban tree populations. Realized climatic niches are calculated by combining bioclimatic data with native tree and urban tree occurrence data. Regression is used to predict the climatic niche of urban tree populations from the climatic niche of native populations.

Results: The realized climatic niche of native tree populations was a good predictor of the realized climatic niche of urban tree populations, although climatic niches are attenuated in urban populations. Urban tree niches were 38–90% wider than native tree niches, with the mean annual temperature niche breath of urban tree populations 3.3 °C (52%) wider than native tree populations.

Main conclusions: Urban trees are planted in climates that are outside the realized climatic niche of native populations. Temperature remains a strong filter on urban tree populations across the full temperature range. Temperature increases attributable to the combined effect of the urban heat island and global climate change are likely to have a substantial impact on urban tree populations around the globe. This is particularly true for temperate cities, where cold climate trees are planted near the upper limits of their realized temperature niches.

KEYWORDS
climate change, climatic niche, global environmental change, temperature, urban ecology, urban heat, urban trees

1 | INTRODUCTION

Temperature and rainfall are globally important determinants of the biogeographical distribution of tree species (Woodward & Williams, 1987). Current theory suggests that in urban areas, minimum annual temperatures limit the distribution of urban tree species, whereas rainfall deficit can potentially be overcome by irrigation (Jenerette et al., 2016). In all cities, the combined effect of the urban heat island and global climate change is resulting in an increase in ambient temperatures (Peng et al., 2012). This could lead to an expansion in the planted distribution of some tree species that will now be able to be survive in (formerly) colder cities (Jenerette et al., 2016). However, it is currently unclear whether an increase in urban temperatures will also restrict the distribution of some cold-adapted tree species or species close to their thermal maxima. A broader understanding of climatic limits to the distribution of urban tree species will enable better prediction of the likely positive and negative effects of increasing temperatures on the world's urban trees. In turn, this will inform future tree selection by urban land managers to withstand increasing temperatures better and to maintain the provision of urban ecosystem services and the function of urban ecosystems.

A climate tolerance and trait choice (CTTC) hypothesis has been proposed to explain the distribution of urban trees (Jenerette et al., 2016). This hypothesis states that in very cold climates, winter minimum temperature is a strong environmental filter, whereas in temperate climates the temperature filter is weak (where irrigation is available) and species distribution is determined more by aesthetic traits (e.g., showy flowers) that influence human decision-making. Although Jenerette et al. (2016) provide empirical evidence from North America to support their hypothesis, they call for a study of trees in globally distributed cities to extend macroecological theory. Other studies of urban vegetation suggest that temperature remains an important environmental filter of plant species across all climates (Kendal, Williams, & Williams, 2012; Ramage, Roman, & Dukes, 2013). Likewise, in natural forest ecosystems, plants respond to changes in temperature in all climates, not only at temperature extremes (Danby & Hik, 2007; Fei et al., 2017; Millar, Westfall, Delany, King, & Graumlich, 2004).

In natural forests, drought is a major cause of tree mortality, and interactions between increasing temperatures and drought are leading to rapid range shifts in the natural distributions of many tree species (Adams et al., 2009; Fei et al., 2017; Williams et al., 2012). In urban forests, drought is also thought to be a major cause of poor tree health and mortality, although sustainability concerns are leading to demands for unirrigated landscapes (Vogt et al., 2017). In response, research on climate change adaptation in urban forests has focused on selecting drought tolerant species (e.g., Roloff, Korn, & Gillner, 2009). Yet existing studies have found little effect of precipitation on urban tree distributions (e.g., Jenerette et al., 2016; Kendal et al., 2012), and the role of precipitation in the distribution of urban trees remains unclear.

Tree species are unlikely to occupy fully all of the areas for which they are climatically suitable within their native (historically known) range for a variety of historical, biological and geographical reasons (Svenning & Skov, 2004). For example, although a location might be climatically suitable for a tree species, biotic interactions, such as interspecific competition and herbivory, might limit the ability of that tree species to grow and reproduce. The climatic conditions within which a species is found are described as its realized climatic niche and are distinct from its fundamental climatic niche, the climatic conditions that the species can tolerate (Hutchinson, 1957). The climatic niche can be conceptualized as an n-dimensional hypervolume, with axes mapped to particular climatic variables (e.g., mean annual temperature, annual rainfall). Climatic niches can be characterized by values for position, breadth and limits (Thuiller, Lavorel, & Araújo, 2005). Niche position is

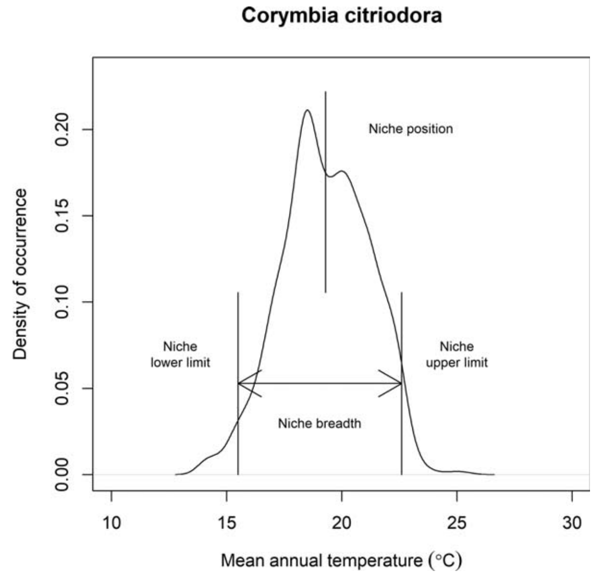

FIGURE 1 Climatic niche values for mean annual temperature of native populations of *Corymbia citriodora*

the average climatic conditions within the niche, niche limits are the upper and lower values of the climatic conditions within the niche, and niche breadth is the range (difference between upper and lower limits) of niche values, often calculated independently along each axis (Figure 1). A growing number of studies analysing species climatic niches or modelling habitat suitability have demonstrated that niche breadth and niche position can vary between native (historically known) populations and populations outside their native ranges (Beaumont, Gallagher, Leishman, Hughes, & Downey, 2014; Bocsi et al., 2016; Gallagher, Beaumont, Hughes, & Leishman, 2010).

Urban trees are often cultivated in places that are geographically distant from their native range (Kendal et al., 2012). Comparison of the climatic niches of native and urban tree populations provides a valuable opportunity for understanding differences between the realized and fundamental niches of tree species, and a better understanding of the climatic limits of urban tree species. Cultivating a given tree species within a city can overcome biotic constraints, biogeographical barriers to seed dispersal and ecological seed germination requirements (e.g., climate-related seed dormancy, fire) that may restrict the native distribution of that species. As a consequence, we hypothesize that the realized climatic niches of urban tree populations will be broader than that of their native populations and therefore provide a closer approximation of the species' fundamental ecological niche. It is less clear what the relationship between the niche position of native and urban tree populations will be, as this can vary with species-level factors limiting or skewing native distributions (Thuiller et al., 2005) and with historical and cultural factors influencing urban distributions (Kendal et al., 2012). A better understanding of the climatic niche limits of urban tree populations will also provide useful information for the planning and selection of tree species that are better adapted to future urban climates.

In this study, we explore how the urban climatic niches of a global suite of urban tree species ($n = 203$ species) are shaped by the climatic niche of their native populations. In particular, we ask:

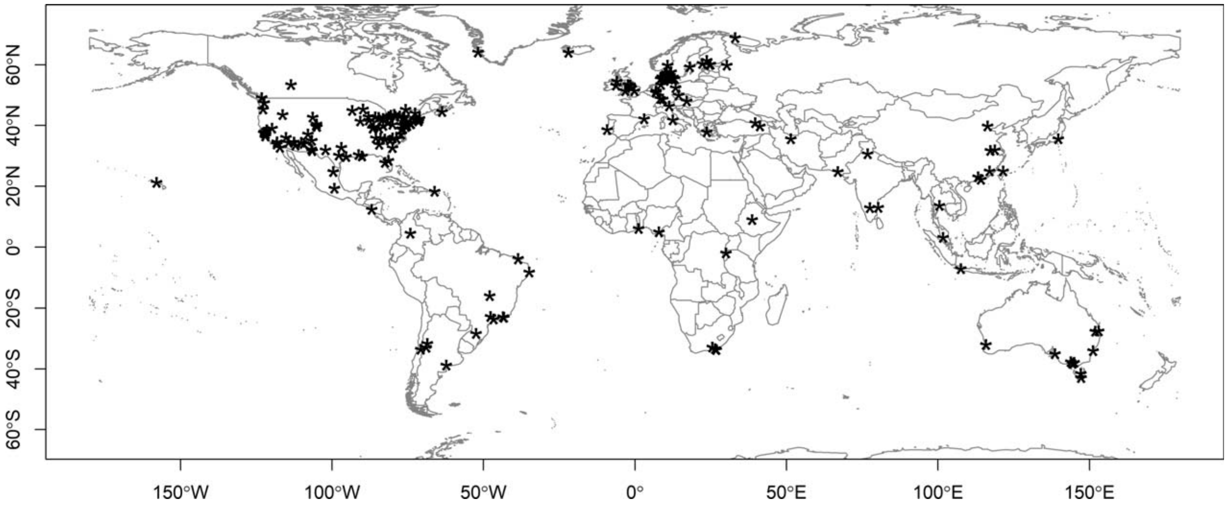

FIGURE 2 A map of the cities included in the study

1. How are the climatic niche positions of native and urban tree populations related?
2. How are the breadths and limits of climatic niches different between native and urban tree populations?
3. How are the climate niches of urban trees arrayed along a 0–30 °C mean annual temperature gradient?

2 | METHODS

2.1 | Datasets used

Urban tree species records were compiled from publicly available urban tree inventories ($n = 433$) of parks, streets and gardens from around the world (182 cities, 44 countries, six continents; Figure 2; Supporting Information Appendix S1) published in journal articles, book chapters and government reports (Supporting Information Appendix S2). These were compiled over a 10-year period through review of the academic literature and grey literature, through internet searches and through electronic news, forums and newsletters targeting the urban forestry industry. Studies that focused on remnant (e.g., conservation) or spontaneous (e.g., invasive) species were not included in the analysis. Although some remnant or spontaneous trees may have been recorded, the compiled dataset is largely composed of deliberately planted trees occurring in urban streetscapes, parks and residential gardens. All native occurrences for the same suite of species were extracted from the Global Biodiversity Information Facility (GBIF) using the *dismo v1.1.4* package in R 3.3 (Hijmans, Phillips, Leathwick, & Elith, 2016) in January and February 2017. The GBIF database includes data from a wide range of sources, including herbarium records, scientific studies and citizen science projects, and includes both native and adventive populations (Franklin, Serra-Diaz, Syphard, & Regan, 2017).

To extract native occurrences only, we obtained published native range spatial polygons for a sample of urban tree species (Supporting Information Appendix S3) that occurred in at least three cities. Native range polygons were obtained for the U.S.A. ($n = 107$) from Little (2016) and for Europe ($n = 21$) from the European Forest Genetic Resources Programme (2016). Native range spatial polygons were manually constructed for species ($n = 75$) from native range information available in published floras for Australian, South American, African and Asian species (e.g., Chippendale, 1988; Missouri Botanical Garden, 2017). The coordinates of GBIF points were standardized to the same 2.5 arcmin grid as the climate data (below), and all duplicate records removed. As there were many GBIF records from locations much hotter or colder than our cities, and some records from wetter or drier places, all GBIF records with a mean annual temperature warmer than our hottest city (Chennai, India 28.6 °C) or cooler than our coldest city (Nuuk, Greenland −1.2 °C), or with annual precipitation less than our driest city (San Juan, Argentina 96 mm/year) or more than our wettest city (Taipei, Taiwan 2,720 mm/year), were removed. GBIF records before 1950 were also removed for better alignment of the temporal extent of the data. Lastly, only GBIF records occurring within these native range polygons and outside urban areas (identified as those occurring within urban polygons derived from MODIS satellite imagery; Schneider, Friedl, & Potere, 2009) and urban tree inventory points occurring outside the native range polygons (72% of all records) were retained in the analysis. In total, 203 tree species were included in the final analysis, associated with 3,675 urban tree inventory species occurrence records and 250,857 GBIF records.

To determine climatic niches, 19 bioclimatic (BIOCLIM) variables were extracted for every city centre and species occurrence record from the WORLDCLIM database at a resolution of 2.5 arcmin (Hijmans, Cameron, Parra, Jones, & Jarvis, 2005). BIOCLIM data have been widely used in global studies of climatic drivers of natural and invasive plant species distribution (Beaumont et al., 2009; Booth, Nix, Busby, Hutchinson, & Michael, 2014; Jeschke & Strayer, 2008). BIOCLIM values for the 19 variables were extracted at all GBIF points recorded within native range polygons, and for urban populations at each city centre where the species had been recorded in an urban tree inventory. The distribution of BIOCLIM variables at GBIF points and in cities is in Supporting Information Appendix S4.

2.2 | Data analyses

All data analyses were conducted in R 3.3 (R Core Team, 2017). Taxonomy was standardized against The Plant List (www.theplantlist.org) using the *taxonstand v1.8* package (Cayuela, Stein & Oksanen, 2017). We calculated the range of each BIOCLIM variable across all urban environments sampled. Mean annual temperature (BIOCLIM1) and annual precipitation (BIOCLIM12) were selected as useful and widely used climatic measures in plant biogeography that are easily interpretable (Woodward & Williams, 1987). Other important climatic variables were determined using a principal components analysis (PCA) of all city BIOCLIM variables and selecting a single variable loading heavily on each component (Supporting Information Appendix S5).

For each tree species, we calculated climatic niche position and breadth separately for native and urban populations, for each BIOCLIM variable of interest. Niche position was calculated as the mean value, lower niche limit as the 2.5th percentile, upper niche limit as the 97.5th percentile, and niche breadth as the distance between lower and upper limits (Figure 1). Native climatic niche values were then used to predict urban niche values using generalized linear regressions with a normal error distribution, separately for niche position, lower limit and upper limit, and niche breadth, for each BIOCLIM variable of interest. We note that these niche parameters are not independent; all temperature variables are correlated to some extent, and niche parameters are likely to behave in a similar manner. As there were large differences in the sample size of native and urban populations, for each species the larger sample was randomly subsampled to match the smaller sample size 999 times, and mean niche values were calculated across all permutations.

The spread of urban species occurrence across a mean annual temperature gradient was determined by assessing the overlap of each species' niche with 1 °C mean annual temperature bins (from 0 and 30 °C). Tree species were considered present at a mean annual temperature if their realized urban or native mean annual temperature niche overlapped the 1 °C bin. We measured turnover in species composition along this temperature gradient by calculating the number of tree species present, gained and lost for each 1 °C bin.

3 | RESULTS

Three components were chosen for the PCA as being both easily interpretable and able to explain a large proportion of the variation in the data (Supporting Information Appendix S5): mean temperature of the coldest quarter (BIOCLIM11) loaded heavily (0.95) on component 1, precipitation of the driest quarter (BIOCLIM17) loaded heavily (0.91) on component 2, and mean maximum temperature of hottest month (BIOCLIM5) loaded heavily (0.79) on component 3. Mean annual temperature (BIOCLIM1) and annual precipitation (BIOCLIM12) were relatively well correlated with component 1 (loading = 0.93) and component 2 (loading = 0.76), respectively.

3.1 | Niche positions

The niche positions of native tree populations were good predictors of the niche positions of urban populations for all temperature variables (Figure 3; Table 1). There was collinearity within temperature and precipitation niche position variables, and similar patterns were expected across the models. However, there were some differences in the strength of relationship for different temperature variables. Mean temperature of the coldest quarter had the strongest relationship, and the mean annual temperature also had a strong relationship. The mean maximum temperature of the hottest month, precipitation of the driest quarter and annual precipitation of native and urban tree populations had a moderate relationship (Figure 3; Table 1).

There were some consistent differences between the climatic niche positions of native and urban tree populations (Figure 3). All niche position relationships had a slope less than one and a positive intercept, indicating a shift away from climatic extremes in urban tree populations. Tree species whose native populations are found in colder climates can commonly be found in cities whose temperatures are up to 5 °C warmer than native populations. This shift away from temperature extremes is also present in hotter climates, although model relationships were relatively weak.

Niche positions for precipitation variables among urban populations were also consistently different from native populations of the same species. A shift away from precipitation extremes was identified; species with native populations from very dry areas are found in somewhat wetter cities, whereas species with native populations from wet areas are found in much drier cities. This is strongly related to total precipitation, i.e. species from wetter climates (annual precipitation $>$ 1,000 mm/year or driest quarter $>$ 150 mm/quarter) are found in much drier cities, whereas species from drier climates (annual precipitation $<$ 500 mm/year or driest quarter $<$ 100 mm/quarter) are generally found in cities with similar or slightly higher precipitation levels.

3.2 | Niche breadths

The climatic niche breadths (as measured by the difference between the 97.5th and 2.5th percentiles, calculated separately for each BIOCLIM variable) of urban tree populations are consistently and substantially wider than those of native populations (Figure 3; Table 2; Supporting Information Appendix S6). Niche breadth was on average 51% wider along the mean annual temperature axis of urban than native populations, 64% wider for the temperature of the coldest quarter, and 90% wider for the maximum temperature of the hottest month. Likewise, the mean niche breadth was 38% wider along the annual precipitation axis of urban compared with rural populations, and 47% wider along the precipitation of the driest quarter axis. Again, owing to collinearity within temperature and precipitation niche breadth variables, similar patterns were expected across the models.

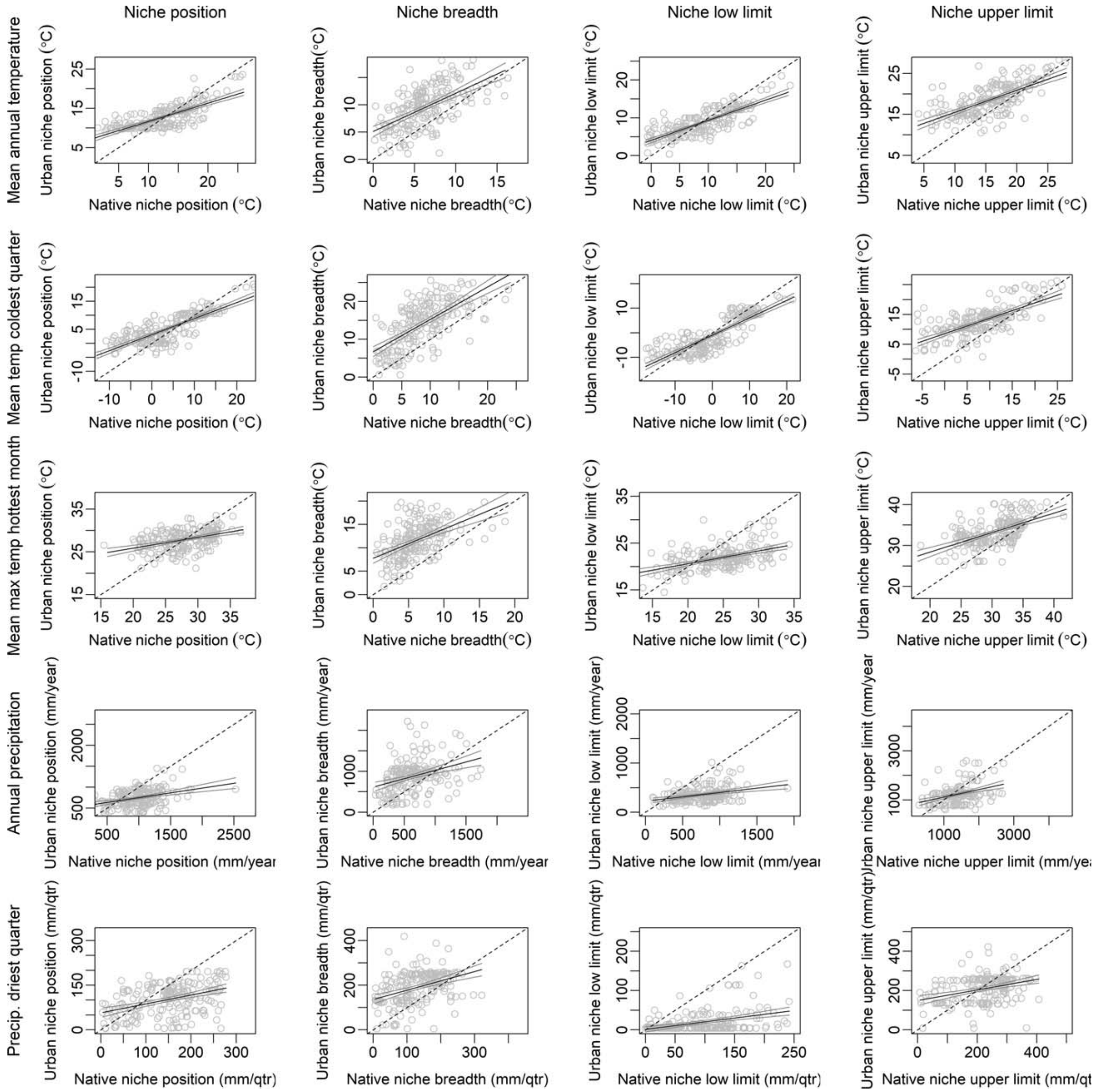

FIGURE 3 Relationships between native and urban niche position for climatic variables. The 95% confidence interval of the mean is shown, and a 1:1 relationship is shown as a dashed line

The relationship between the niche breadths of rural and urban tree populations varied along a gradient of niche breadth (Figure 3). With the exception of the mean temperature of the coldest quarter, species whose native populations have narrow climatic niches tended to have urban populations with broader climatic niches. In contrast, species whose native populations have very broad climatic niches tended to have urban populations with similar climatic niche breadth. There were few species whose urban tree populations had smaller niche breadths than their native populations (i.e., there were few points below the 1:1 line in Figure 3).

Unsurprisingly, the temperature niche limits (upper limit = 97.5th percentile, lower limit = 2.5th percentile) of native and urban tree populations followed similar patterns to niche position and breadth for each BIOCLIM variable. The limits of mean temperature of the coldest quarter and mean annual temperature had the strongest relationship (Figure 3; Table 1). There was a weaker relationship with mean maximum temperature of the hottest month. The limits of precipitation variables also had weaker relationships between native and urban populations. Temperature and precipitation niche limits were less extreme in urban tree populations than in native populations. Although the mean minimum of the coldest quarter of native tree populations remained the best predictor of the lower limit of urban tree populations, mean annual temperature was a slightly better predictor of upper niche limits.

TABLE 1 Regression parameters for BIOCLIM variables when predicting urban population niche values from native population niche values

Niche variable	Name	BIO1	BIO11	BIO5	BIO12	BIO17
Position	Intercept	7.00	3.11	20.8	519	57.1
	Intercept.se	0.39	0.25	1.08	41.9	7.57
	Coefficient	0.47	0.57	0.25	0.23	0.30
	Coefficient.se	0.03	0.03	0.04	0.04	0.05
	D^2	0.56	0.64	0.18	0.14	0.17
Breadth	Intercept	5.13	6.69	7.8	615	136
	Intercept.se	0.47	0.66	0.53	55.4	10.1
	Coefficient	0.70	0.86	0.62	0.41	0.42
	Coefficient.se	0.07	0.07	0.08	0.08	0.07
	D^2	0.35	0.44	0.24	0.12	0.16
Lower.limit	Intercept	4.03	−0.98	15.1	225	1.16*
	Intercept.se	0.30	0.27	0.83	27.7	3.40
	Coefficient	0.53	0.71	0.27	0.18	0.19
	Coefficient.se	0.03	0.03	0.03	0.04	0.03
	D^2	0.64	0.71	0.25	0.11	0.16
Upper.limit	Intercept	10.1	8.57	18.9	806	149
	Intercept.se	0.67	0.39	1.55	78.5	12.0
	Coefficient	0.54	0.52	0.48	0.31	0.27
	Coefficient.se	0.04	0.04	0.05	0.05	0.05
	D^2	0.46	0.50	0.31	0.14	0.12

Note. D^2 is the proportion of deviance explained; $D^2 = (D_{null} - D_{model})/D_{null}$. Intercept.se = intercept standard error, Coefficient.se = coefficient standard error. All values are significant at $p < 0.001$ except $^*p > 0.05$.

3.3 | Niche occurrence along a temperature gradient

There are few tree species that occur in very cold temperatures; only 13% of species had a mean annual temperature niche that overlaps 3 °C (Figure 4a). As mean annual temperatures increase, more species start to occur as temperatures move past their lower niche limits (Figure 4b). Above 11 °C, some species start to reach their upper niche limits and no longer occur. Most urban tree species (83%) in this study have climatic niches that include a mean annual temperature bin of 14 °C. Between 13 and 16 °C, there is a rapid turnover of species as colder climate species begin to drop out, and warmer climate species start to occur. Above 16 °C, colder climate species continue to reach their upper niche limits, and relatively few new species start to occur.

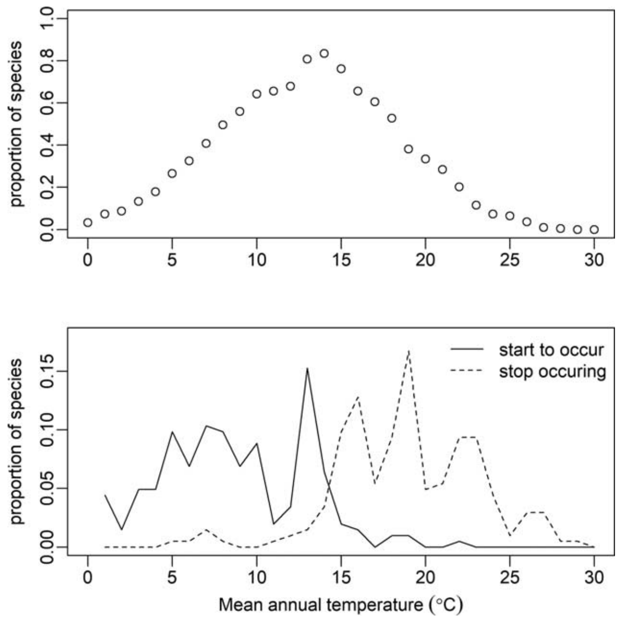

FIGURE 4 The proportion of species in 1 °C mean annual temperature bins that (a) are known to occur (combined native and urban niche) and (b) start to occur (enter niche) or stop occurring (leave niche) in urban plantings

There are few species that occur in very hot temperatures; 23 °C is warmer than the upper limit of the mean annual temperature niche of 89% of species in this study.

4 | DISCUSSION

We found that temperature continues to constrain the distribution of all urban trees studied, not only those occurring in very cold cities. Minimum and mean annual temperatures of native tree populations are good predictors of the urban climates where those trees are planted. This is particularly important, because the combined effect of the urban heat island and global climate change is likely to lead to temperature increases of at least 3–5 °C in many cities (Peng et al., 2012), which is half the mean annual temperature niche breadth of the species included in the present study. Temperature niches are broader in urban tree populations than in native tree populations, but niche positions are

TABLE 2 Mean climatic niche breadths (97.5th–2.5th percentile) for selected BIOCLIM variables

Variable	Natural populations	Urban populations	Percentage of species where urban niche is wider
Mean annual temperature (BIOCLIM 1; °C)	6.3 ± 3.2	9.6 ± 3.7	82%
Minimum temperature of the coldest quarter (BIOCLIM 11; °C)	8.6 ± 4.6	14.0 ± 6.0	88%
Maximum temperature of the hottest month (BIOCLIM 5; °C)	6.1 ± 3.0	11.6 ± 3.8	94%
Annual precipitation (BIOCLIM 12; mm/year)	636 ± 326	875 ± 382	77%
Precipitation of the driest quarter (BIOCLIM 17; mm/yr)	129 ± 68	190 ± 73	79%

Note. Standard deviations are shown.

attenuated at temperature extremes; trees from very cold places tend to be planted in warmer cities, whereas trees from very hot places tend to be planted in cooler cities. Many cold climate trees start to disappear in temperate cities. These findings have important implications for the future vulnerability of some urban tree species to increasing temperatures owing to global environmental change in all climates.

Our results are partly consistent with the proposed CTTC theory to explain the distribution of urban trees (Jenerette et al., 2016). Minimum temperatures are important; however, our results also demonstrate that this temperature filter continues to be a powerful influence on the distribution of urban trees across all climates, not only cold ones. The difference in these findings may be attributable to the larger global dataset of 196 cities across a wide range of temperatures compared with the North American dataset of 20 cities used by Jenerette et al. (2016). The findings of our study do not invalidate the trait choice hypothesis in moderate climates, because people in temperate cities have a larger pool of suitable tree species to choose from, which would allow greater consideration of aesthetic traits.

The temperature niche position of native tree populations was a good predictor of the niche position of urban populations of the same species. In particular, the mean temperature of the coldest quarter and the mean annual temperature of urban tree populations were similar to native populations. Minimum temperature has been identified as a key driver of the distribution of urban trees (Jenerette et al., 2016; Ramage et al., 2013), because it relates directly to tolerance of freezing temperatures and strongly influences plant growth and survival in colder areas. However, mean annual temperature may be a good proxy for a wide range of other climate-related mechanisms that continue to limit the distribution of urban trees in all climates. Physiological responses, such as dehydration, xylem cavitation, heat damage and carbohydrate exhaustion, can vary among species along temperature gradients (Allen et al., 2010). Higher temperatures may also influence the distribution and abundance of pests and diseases, increasing these threats for some urban tree species (Tubby & Webber, 2010). As higher temperatures often contribute to tree moisture stress, this can further influence the susceptibility of trees to herbivory or pathogens (Dale & Frank, 2014). Interestingly, there was no evidence that urban tree distributions have responded to urban heat, which should allow urban trees to be planted in cities that are colder than natural populations.

Climatic niche breadths were consistently and substantially wider in urban tree populations. Species with very narrow niche breadths among their natural populations had urban populations with much wider temperature and precipitation niches, whereas species with very large native niche breadths had similar wide niche breadths in urban populations. This is consistent with the assumption that cultivation overcomes some of the limitations to dispersal in natural populations and allows species to occupy a greater extent of their fundamental niche.

The upper and lower niche limits for temperature and precipitation were also attenuated in urban tree populations (Figure 3). Tree species naturally occurring in cold areas are more often planted in cities that are warmer than their natural temperature niche. Likewise, although with more uncertainty, tree species naturally occurring in hot areas are more often planted in cities that are cooler than their native temperature niche. Perhaps counter-intuitively, these data suggest that the current urban forest populations found in cool temperate cities could be more vulnerable to increasing temperatures than the urban forests of warmer climate cities. Although it is true that more tree species may start to fall within the temperature niche of cooler cities as their temperatures increase, many of the cold climate tree species currently planted in these cities are at, or close to, the upper limit of their known temperature niche. In contrast, tree species from warmer areas tend to be planted closer to the lower limits of their temperature niche of their native range, and thus may have more capacity to tolerate future temperature increases.

Precipitation is often discounted as a useful predictor of urban tree distributions (Jenerette et al., 2016; Kendal et al., 2012). Our findings provide further empirical support for this. We found that the precipitation niche position, breadth and limits of native tree populations were weak predictors of the precipitation niche variables of urban tree populations. Urban trees are regularly planted in cities that are much drier than their native populations. This could be explained by the use of irrigation. Although irrigation data are not currently available to test this at a global scale, many of the urban tree data used in the study are from locations that are less likely to receive irrigation. Irrigation may be common in drier cities in affluent countries (e.g., south west U.S.A.; Jenerette et al., 2016) but is less likely in the areas contributing to the inventory data used in this analysis, including land uses such as street trees, in cooler climates, and in developing countries.

In combination, these findings are consistent with a growing body of research demonstrating that the realized climatic niches of species can change when they are introduced to new environments (Beaumont et al., 2014; Gallagher et al., 2010). Many of the potential barriers that restrict native trees from fully occupying their fundamental climatic niche are alleviated through cultivation in urban tree populations: they are actively dispersed by people around the globe, germination barriers are overcome by nursery propagation, and the importance of species competitive interactions is often diminished. Although niche breadths were clearly wider, the realized climatic niches of native tree populations continue to be useful predictors of the realized niches of urban populations. Some tree species may thrive in urban environments that are dramatically different from their native environments, but these results show that the vast majority of urban tree species are constrained to climatic environments that are related to their native ranges.

The strong relationship between temperature niche position and niche limits in native and urban populations suggests that global environmental change could lead to large changes in the composition of urban forests in some cities. The magnitude of the urban heat island effect, which is potentially greater than global climate change in many cities (Peng et al., 2012), means that temperature-driven changes to urban tree composition could exceed those predicted in natural forest areas (e.g., Allen et al., 2010). Management responses to these changes are likely to have flow-on effects for urban ecosystems. The introduction of new tree species to an area for use in urban plantings has been an important source of plant invasions worldwide (Čeplová, Lososová,

& Kalusová, 2017; Dehnen-Schmutz, Touza, Perrings, & Williamson, 2007) and can have detrimental effects on native ecosystems (Moser et al., 2009). Conversely, species that are lost from an urban area could provide important ecosystem functions, such as food or habitat for other organisms (e.g., Stagoll, Lindenmayer, Knight, Fischer, & Manning, 2012). The possibility of rapid management response to magnified environmental change in urban forests means that urban ecosystems could be particularly useful for investigating a range of ecological effects of increasing temperatures and management responses to this change. Urban trees are an important social and ecological component of urban areas, and increased understanding of the risks and opportunities created by a changing environment will have important implications for our cities globally.

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DATA ACCESSIBILITY

Urban tree occurrence data can be obtained for the species listed in Supporting Information Appendix S3 from the list of publications in Supporting Information Appendix S2. Native species occurrence data can be obtained for the species listed in Supporting Information Appendix S3 from the publically accessible Global Biodiversity Information Facility.

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BIOSKETCH

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SUPPORTING INFORMATION

Additional Supporting Information may be found online in the supporting information tab for this article.

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