Scaling Up Climate Adaptation through Sustainable Urban Forestry

by

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A project submitted
in partial fulfillment of the requirements
for the degree of
Master of Science / Master of Landscape Architecture
(Environment and Sustainability)
in the University of Michigan

April 2025

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Abstract

Due to the intense and rapid onset of climate change, urban forests are suffering. City trees are experiencing extreme conditions, resulting in reduced lifespans and reduced ability to perform essential ecosystem functions within these city landscapes, where they are arguably needed the most. For trees to benefit the ecosystem the most, they need to be planted in the most suitable climate, which is shifting globally. Cities should begin planting more resilient species of trees now, based on how their climate is expected to shift. Our project team used existing information to create tools intended to help aid landscape architects in selecting the best species of tree to plant in their city, including *Climate Change Scenario Maps*, a *Tree Species Frequency Distribution Table*, and a website to host these tools, along with the *Plant Your City Explorer*, and other useful information. These tools were created with research into city trees and parsing which species are most commonly used in different subclimates. The climate categories are based on the Köppen Geiger Climate Classifications, which were also used to isolate and create the aforementioned maps. These tools are meant to be the first versions of more robust, detailed tools created over time as more information and resources become available to fill the needed gap of species selection tools at the global level. These tools are currently useful for helping to plant and prepare more resilient urban forests in the face of climate change.

1. Introduction

1.1 Benefits of Urban Trees

Like any other organism, trees have a specific geographic range in which they are most suited to grow and thrive, maximizing the efficiency of their benefits. In an urban environment, these benefits include: stabilizing soils to prevent erosion, filtering air pollution and sequestering carbon while providing fresh oxygen, filtering runoff water pollution, and reducing air temperatures, providing cooling (Livesley, 2016). Additionally, they provide food and habitat for small organisms, aesthetics for the general appearance of a city, and greenspaces for human interaction, which has positive effects on mental, physical, and emotional health, especially when in an urban environment, or, concrete jungle (Barton & Rogerson, 2017; Lüttge & Buckeridge, 2023). However, as global temperatures and precipitation regimes shift, many tree species are struggling to thrive in what was once their native environments.

1.2 Climate Change & Urban Heat Island Effect

The importance of cooling is especially important when considering elements like the Urban Heat Island Effect (UHI) and urban infrastructure. UHI is a phenomenon where an urban area has significantly warmer air temperatures compared to the surrounding rural areas (Shreevastava et al., 2021). The temperature difference can be anywhere from 2°C to 10°C (Chapman et al., 2017). This is primarily due to the amount and concentration of heat-absorbing-and-reflecting surfaces found within a city, such as asphalt, metal, concrete, or glass. Similarly, urban areas tend to have more industry, cars, and other heat-releasing practices that then also get trapped within absorbent surfaces. The issue lies in a positive feedback loop where as temperatures increase, it takes more energy and money to run industry practices or to cool buildings down (Khan et al., 2025), therefore exacerbating UHI and often resulting in electrical black outs during the hottest summer months. Additionally, intense heat can reduce the durability and lifespan of industrial materials, leading to raised expenses in needing to update infrastructure more frequently compared to if the temperatures were more regulated (Khan et al., 2025).

Climate change is expected to continue raising global average temperatures (Khan et al., 2017), which has serious implications of also creating an even more stifling urban environment. Not only is this inefficient energy-wise, but it poses serious risks for human health in terms of heat-related illnesses and deaths. Additionally, urban areas are expected to grow in size and population, which increases the area of effect on the environment and to humans (United Nations, 2014). Urban trees are a top method to combat this issue–trees with large canopies are chosen to be able to cast shade over wider areas, as well as absorb UV rays and heat without redistributing or reflecting them, as well as the other benefits mentioned previously that trees can provide to an ecosystem. The right tree is important, but planting it in the right place is equally important to the health of the tree, as well as protecting city infrastructure (Barona, 2015). Trees planted close to buildings can help to improve energy efficiency, but planting too close can cause damage or stress to the tree, or potential damage to the building. Since trees are such an important tool to be used in combating climate change and UHI, it is important to understand how the trees are being affected, and the best management practices to ensure cities get the most out of their trees.

1.3 Effect of Climate Change on Urban Trees

Trees are known for their resiliency, which is a main reason why they are chosen to be planted in cities. They have to be able to survive in adverse conditions: poor soil and air quality, drought or flooding conditions, pests and diseases, or damage from other sources (Esperon-Rodriguez et al., 2022). Climate change will only make these issues worse. Higher air temperatures, as outlined previously, are generally correlated with worse air and water quality, as well as drier soils and more frequent drought conditions.

However, climate change is also enabling more severe storm events more frequently, which increases the chances of flooding, especially with the amount of impervious surface that is within a city. Impervious surfaces are any materials that do not allow water to penetrate the soil, thus causing runoff. The speed of flow increases the longer the water is in contact with impervious surfaces, which risks erosion when the water finally comes into contact with sediment. More extreme weather also leads to more damage to tree branches or uprooting. Besides the physical conditions, climate change will also affect the species that are within an ecosystem. As temperatures increase, different species of pests and other organisms can move northward, being introduced to ecosystems where they were not present previously, leaving the trees vulnerable to said pests and diseases, as well as browsing (Lüttge & Buckeridge, 2023). All these conditions lend themselves to the worsening of tree health, shortening of their lifespan, and reduction in ecosystem benefits, but the trees themselves are also being affected in terms of where they can and cannot grow.

Hanberry (2024) has found that 36 tree species are expected to lose climate space, while 64 species gain climate space, and 19 remain relatively stable. This means that those 36 species are going to lose the climate in which they grow and thrive the best in, while the 64 species will have a greater area in which they will be able to grow. With the changing distribution of trees, it presents a problem where the climates of those 36 tree species will lose the species accustomed to the area, creating a hole in the ecosystem for different species to fill. For all intents and purposes, they can be seen as ‘invasives’, albeit more likely on a small scale. Regardless, introducing a new species into an ecosystem may present a host of issues including invasion, altering of the foodweb or physical features of the ecosystem. The 64 species expected to gain climate space are likely going to be the species taking over.

1.4 Existing Resources

There are various tools currently available that are specialized for species selection in certain areas of the world. For example, the *Which Plant Where* database is an Australian plant selection tool that is aimed to help industry experts make informed decisions on the best species of plants for their cities and urban areas. The goal is to create more resilient urban forests in regard to climate change. This tool focuses specifically on plants that would be useful for Australia. Within the United States, different resources have been built for different states, such as the *SelecTree* tool created by California Polytechnic State that is specific to California. However, there is currently no tool for similar use at the global level.

Tree inventory data is more robust, specifically due to sources like the Global Urban Tree Inventory, or GUTI (Ossola, 2020) and TreeGOER (Kindt, 2023). The GUTI project team has done robust research on the species of trees that are present within 473 urban areas around the world, amounting to a total of 4,734 species total within the

database. TreeGOER is a database that documents preferred environmental conditions for 48,129 tree species. However, these two examples are just inventories. They are not meant to be used as selection tools like the previous examples given.

There is data available at a global level for tree species, but no selection tool such as on a smaller scale. This demonstrates the need for that tool. The importance of understanding climate change at a global scale can also help to build more resilient urban forests. Knowing that climate change is causing different regions to experience different climate types, it stands to reason that using information from comparable climates would be an effective way to best plan how to adapt a city's urban forest. Using the projected climate shift for a city to then inform which trees to plant minimizes the guesswork, especially if there is a tool that houses all of that information for decision makers.

This idea forms the foundation of our project. The rapid changes in climate change and the drastic projections have created a need for updating urban forestry infrastructure. While there have been solutions on smaller scales, nothing seems to be available at a global scale, which is necessary for understanding global climate trends and global urban forestry practices. We aim to identify climate-resilient tree species best suited for cities experiencing significant climatic shifts. By aligning tree selection with future climate conditions, we aim to support urban forestry strategies that enhance resilience and maximize ecosystem services.

2. Deliverables

The primary deliverables of this project are as follows:

2.1 Climate Shift Scenario Maps

These maps were created based on the Köppen-Geiger Climate Classifications to isolate areas of the world that are expected to experience shifts in (a) temperature or (b) precipitation. Each map is then broken down into how each of these conditions will be changing in that region, as depicted by the legend.

2.2 Tree Species Frequency Distribution Table

This is the primary **tool** that came from the efforts of this project. The goal is for landscape architects and urban planners to be able to use this tool to better identify tree species to plant in their cities based on their projected climate shift. The table is broken down into the Köppen Geiger Classifications along the y-axis, with the species of trees that appeared multiple times through our research along the top x-axis.

2.3 Plant Your City Explorer

This explorer is meant to showcase a handful of cities within our research to visualize their changing climate and what species they might choose to plant. It also utilizes data from the Fitz Lab City Shiny App that compares a current city's climate to a comparable city whose climate they are expected to experience in 2100. With this information, it makes these changes much more tangible and easier to understand as a resident of a city, rather than as an industry professional.

2.4 Final Tools Website

The website was created as a way to host all of the other tools created throughout this project, as well as act as a public hub for education and outreach. There will be pages where the user can access the **Tree Species Frequency Distribution Table, Climate Shift Scenario Maps,** and the **Plant Your City Explorer.** Additionally, it will house information on the Köppen Geiger Classification system, results from a literature review on practices that have already been implemented in updating urban forestry initiatives, and an experimental ArcGIS storymap meant to help visualize the progression of a city's climate shift.

Further details on the creation of these tools will be outlined in sections **3.6, 3.7, 3.8,** and **3.9.**

Additional deliverables came in the form of literature reviews or written reports. These are mainly a compilation of research that we had done throughout the course of the project: a document describing the methods of updating urban forestry practices and climate change resistant cultivar species, or documents detailing micro case studies on cities' species selection projects.

3. Methodology

3.1 Evaluating Climate Shifts

We evaluated climate change impacts by analyzing two Köppen-Geiger climate maps: one representing the 2025 climate conditions and another projecting conditions for 2100. With the help of Xiaohao Yang, a PhD student in Landscape Architecture, we managed to employ an R script (Figure 1) to identify and isolate areas where climate classifications differ between these two maps. This approach enabled us to pinpoint regions expected to undergo significant climate change, facilitating a clearer understanding of potential shifts in climate zones and their implications for environmental systems and species distribution.

```
2100img <- terra::rast('/Users/yangxiaohao/Downloads/drive-download-20240326T202600Z-001/2100.tif')
img2100 <- terra::rast('/Users/yangxiaohao/Downloads/drive-download-20240326T202600Z-001/2100.tif')
delta_ <- img2100 - current
img2100[delta_!=0] <- NA
terra::writeRaster(img2100, '/Users/yangxiaohao/Downloads/drive-download-20240326T202600Z-001/2100_clip.tif')

```

Figure 1. Screenshot of the R script used to identify and isolate differences between 2025 and 2100 Koppen-Geiger climate classification raster datasets

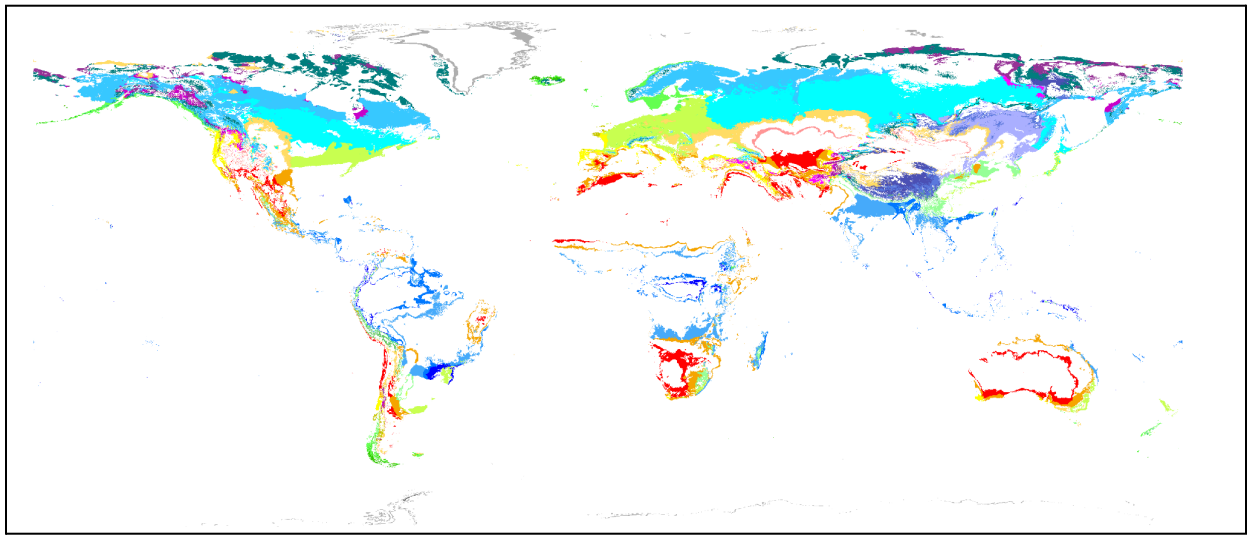


Figure 2. Map showing the areas of the world expected to experience a shift in Koppen-Geiger climate classification between 2025-2100

3.2 Definition of "City" & Choosing Cities

The term "city" carries varying definitions across cultural and administrative contexts. For example, in some countries, a settlement with a relatively small population may be designated as a city for historical or administrative reasons. In contrast, it might be considered a town or a suburban area in others. This variation can lead to inconsistencies when comparing urban forestry characteristics such as tree species richness and canopy cover. A small city in one context may have far fewer species than a similarly sized "town" elsewhere, misleading direct comparisons. Additionally, larger cities are more likely to have accessible urban forestry datasets, allowing for more robust comparative analysis. To ensure consistency and fairness in our analysis, we established a standardized classification system based on population size, rather than local naming conventions.

Using government statistical datasets, we developed the following population-based urban area typology to guide city selection:

- City: 100,000 – 500,000
- Large City: 500,000 - 1,000,000
- Major City: 1,000,000 – 5,000,000
- Metropolis: 5,000,000 – 10,000,000
- Megacity: 10,000,000 – 20,000,000
- Metacity: Over 20,000,000

To avoid inconsistencies in data quality and urban forest scale, we excluded cities with populations below 100,000, as these areas often lack comprehensive urban forestry programs or data infrastructure. For Metacities (e.g., New York, Tokyo), which often span multiple jurisdictions and vast land areas, we assessed these metacities more carefully to ensure the urban tree data reflected a clearly defined administrative or ecological boundary. This approach helped maintain comparability across the dataset.

We filtered cities from the Global Urban Tree Inventory (GUTI) dataset, as these cities have been pre-identified for their relatively high availability of urban tree species data. We recognize that GUTI does not include all global cities, particularly those lacking a complete tree inventory. Thus, we supplemented our selection with an additional set of cities. These supplementary cities were chosen to ensure broader geographic and climatic representation, particularly by aiming for even distribution across the Köppen climate zones, except polar regions (which were excluded due to their low tree species diversity and limited urban forest coverage). In considering data accessibility, we prioritized cities with official or widely available urban forestry documentation in English. Additionally, given our team's composition and language capacities, we included cities where Mandarin is an official language and public documents are more readily accessible. In total, 73 cities were chosen from the GUTI dataset, and an additional 41 cities were chosen from outside the GUTI list, bringing the final sample to 114 cities.

3.3 Literature Reviews

The initial purpose of the literature review portion of our project was to assess what was already known about ideas related to this topic. Areas of interest for our group were as follows:

- Effects of climate change on urban trees
- Ecosystem benefits provided by trees (generally and within an urban environment)
- Stressors trees face within an urban environment
- Urban heat island effect and indices
- Methods of coding or modeling that may be useful for our project
- Interviews with specific individuals relevant to the sustainable urban forestry industry

In addition to these topics, we also looked at resources that already housed tree inventory data, so that we could see where any missing information could be added. The Global Urban Tree Inventory (Ossola, 2020) was a foundation for our research, as the team had already compiled the tree inventory data for various cities around the world. We wanted to work where the GUTI had not yet covered. From there, we began a deep literature search to find tree inventory data on cities *not* listed in the GUTI, and that fit our requirements of 'what a city is', as outlined above.

3.4 Tree Inventory Compilation

Building on our city selection, we compiled a comprehensive dataset integrating urban tree species information and climate stress indicators. Each city entry includes, but is not limited to: Köppen subclimate zone and description, population size, the top 10 most common tree species ranked by total tree counts per species, and Surface Urban Heat Island Index (SUHI) values.

We revisited original inventory sources for cities within the GUTI dataset to extract and re-rank tree species based on abundance. Concerning sources included non-disclosed data or access limitations (e.g., shared under restricted agreements), we substituted open-access sources such as research publications, municipal reports, or open tree maps to compile the species rankings.

For cities not included in GUTI, tree composition data were also gathered from open-access materials, including scientific articles and local government documents. Where detailed species inventories were incomplete or absent, we noted the limitations and accepted genus-level classifications where necessary. All tree listings follow Latin binomial nomenclature, and cultivar names are included when available to ensure taxonomic clarity.

An internal quality control process was used to evaluate each data source before including its data in the compiled tree species rankings. We applied a filtering rubric based on three key criteria:

- Data accessibility (e.g., open-access vs. restricted datasets)
- Confidence scale, categorized as Good, Decent, or Bad based on completeness and clarity
- Source type (e.g., peer-reviewed articles, government website, or open data portals)

This process allowed us to identify credible and up-to-date sources, while managing limitations in cases where only partial or lower-confidence inventories were available.

We integrated Surface Urban Heat Island (SUHI) Index data from remote sensing and climatology studies (Mughal et al., 2020). While not explored in depth in this project,

SUHI represents an urban-scale climate stressor, comparable to climate change, that can influence tree survivability and urban resilience. Thus, it is included in our dataset. It is recognized that multiple factors, including surface albedo, thermal properties of materials, building density, vegetation cover, and anthropogenic heat release, influence SUHI in cities. For example, despite Singapore's leadership in nature-based urban planning, its central business district continues to exhibit high SUHI values due to high development density and human activity.

3.5 Research on Methodology in Updating Urban Forestry Infrastructure

A smaller portion of our project was assessing the changes that are currently occurring, or have already occurred, within the realm of urban forestry. To do this, we wanted to research whether there had been any cultivar species of trees that had been specifically bred with the intent to combat certain effects of climate change, and also research what urban forestry practices cities around the world had begun to implement, or planned to implement, again, specifically because of climate change.

The primary method of this research was a focused literature review for each topic, as well as reaching out to relevant entities. For the literature reviews, we studied a variety of media types including peer-reviewed journal articles, government reports, news articles, and databases to see what information was available about newly-bred cultivar species, as well as infrastructure changes. The idea was to find any commonalities between cities within similar climate zones, either through species of cultivars (or trees in general) being chosen, or if any had taken up similar practices.

After a literature review phase resulted in some general information, we discussed the importance of having input from relevant stakeholders, mainly: nurseries and municipalities. If there was minimal documentation available on the internet, we may have better luck directly reaching out to these entities.

For nurseries, we targeted prominent local companies within Michigan, as well as a handful of national (U.S. Only) companies for the sake of simplicity. The inquiry method varied depending on size of the company–local companies would have a direct email address to contact, whereas some of the larger companies only had a submission box. In either case, we provided background on our project, and inquired the following questions:

- Do you have any knowledge of cultivar tree species having been bred as a direct result of climate change, with the priority of increasing survivability in extreme urban conditions?
- Has your nursery begun to grow any of these species, or have begun to breed alternative species?
- How has species demand changed, and has it impacted the species you choose to grow?

- Have you noticed any changes within the urban forestry landscape due to climate change?
- Any other relevant information they would like to share

In reaching out to different municipalities, we again primarily focused on cities within the United States for ease, but expanded to any cities that were primarily English-speaking. For the municipalities, we tried to identify specific individuals whose titles indicated that they may have an interest in providing information for our project, but just as with the nurseries, some cities only had a general submission form. Various titles that we were looking for included anything within the roles of departments relating to: Sustainability, Environment, Public Works, Urban Forestry, Parks and Recreation, etc. Some cities had more clearly defined roles, whereas others were vague. For the most part, inquiries sent to the wrong department would then be internally forwarded to the correct contact. Similar to the nursery inquiries, we provided background information on our project, and asked the following questions:

- Has your city begun to initiate any policy or infrastructure changes to the way city trees are being planted, *directly because of climate change?*
- Have there been any changes in which species are being planted within the city–if so, how and why were these species chosen?
- Have there been any challenges in implementing these changes?
- Some questions directly related to that city's climate, for example, Phoenix, Arizona, inquiring about water usage or their particularly hot and dry climate
- Any other relevant information they would like to share

3.6 Understanding the Impact of Climate Change on Tree Survivability

To understand the impact of climate change on tree survivability, we utilized two existing Köppen-Geiger climate maps provided by the IPCC, representing current and projected climate conditions for the year 2100. We began by transcribing each Köppen-Geiger climate classification into discrete numerical codes. This translation facilitated the use of the "Compute Change Raster" function in GIS, allowing us to analyze categorical differences between the two maps.

By comparing these maps, we identified which regions are expected to experience significant climate changes and in what manner. This analysis is crucial in determining the future survivability of tree species, as it assumes that trees can only thrive within specific climate ranges. If the climate in a given region shifts outside a tree's tolerable range, the species is likely to struggle or even fail to survive.

The initial outcome of this process was a comprehensive map illustrating all occurrences of Köppen-Geiger categorical changes. We identified 214 distinct climate permutations (Figure A in Appendix). To maintain focus on our project's objectives, we

excluded regions without any categorical changes from further discussion, assuming that tree species in those areas would continue to survive.

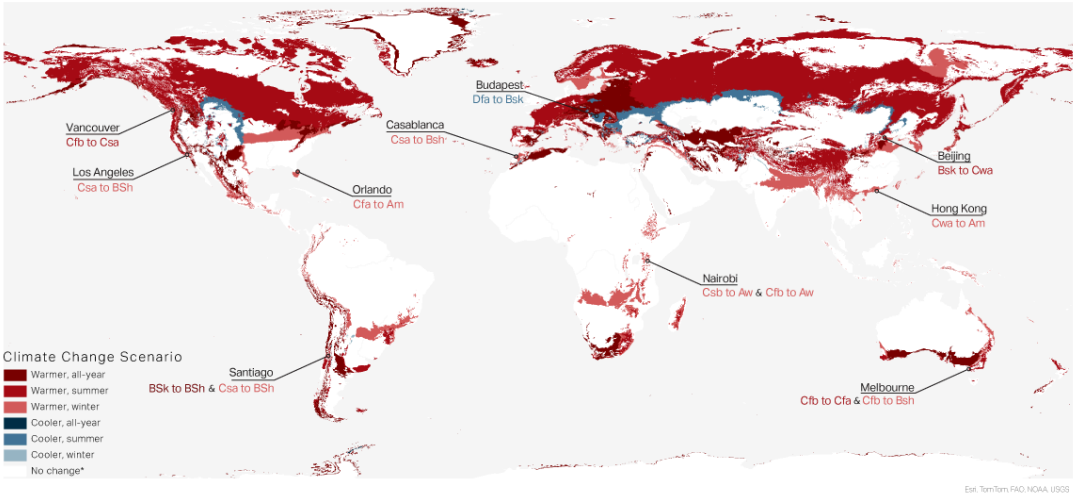


Figure 3. Climate Change Scenario Map depicting areas that will either become warmer or cooler, with specifications as to whether it will become warmer or cooler in the summer, winter, or year-round. A larger version of this map is available in the Appendix (Figure B).

Next, we reclassified all distinct climate shifts into two primary categories: temperature (Figure 3) and precipitation (Figure 4). Using definitions of each Köppen-Geiger classification, we evaluated the "direction" of climate change in affected regions to derive climate change scenarios. For instance, the city of Orlando, currently classified as Cfa (humid subtropical climate), is projected to change to Am (tropical monsoon climate) by 2100. Based on these classifications, we deduced that Orlando will likely experience warmer and drier winters. Consequently, regions undergoing a similar shift from Cfa to Am were reclassified as "warmer winter" under the temperature scenario and "dryer winter" under the precipitation scenario.

The reclassification resulted in two distinct maps illustrating temperature and precipitation change scenarios. These maps are vital for informed decision-making regarding the selection of tree species adaptable to future climate conditions.

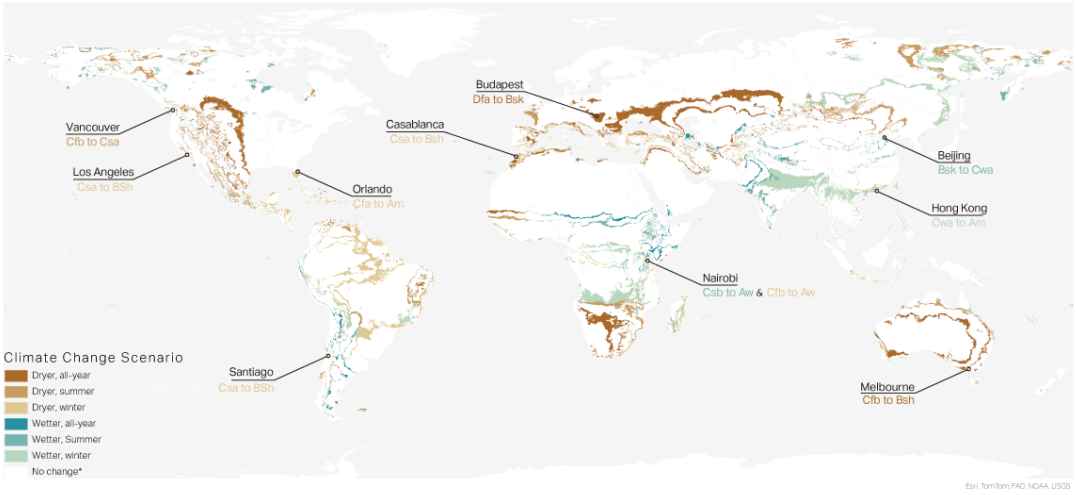


Figure 4. Climate Change Scenario Map depicting areas that will become either drier or wetter, categorized by summer, winter, and year-round. A larger version of this map can be found in the Appendix (Figure C).

3.7 Tree Species Frequency Distribution Table

In order to create a distribution table, we first reclassified the collected data of urban tree species according to Köppen climate type, obtained a new list of tree species and climate relationships, and carried out three data cleanings to ensure that the plants were scientific names of tree species with the correct spelling. Then, we get a Tree Species-Climate Type Table (Details are provided in Appendix Table 1), after that we counted the number of times each tree species appeared in each climate type, and visualized the data (Figure 5). Then, based on analyzing global tree inventory data and the Köppen climate classification system, we explored tree species distribution across 24 climate types. These findings were visualized through species-specific pie charts and heatmaps, which show the preference of species across climate types (Figure 10). This data-driven approach enables planners to match species to local climatic conditions with greater accuracy, enhancing urban forest resilience and biodiversity.

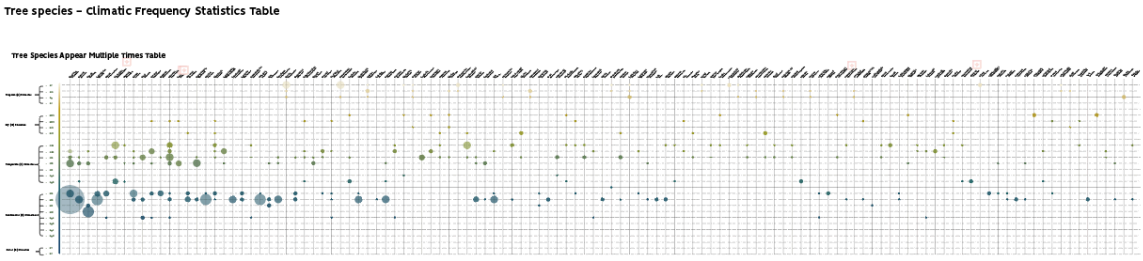


Figure 5. Tree Species Frequency Distribution Table: visualizes the species of trees that are most common per subclimate type. Larger circles indicate the species being more popular in that subclimate. A link will be provided to this table within the Final Tools website for better viewing and use.

3.8 Plant Your City Explorer

The Plan Your City Web Explorer was developed as a key visualization tool to communicate how climate change may affect urban tree suitability across selected cities. Based on the team's city-level forestry and climate database, a subset of cities projected to undergo Köppen climate zone shifts by 2100 was selected.

For each of these target cities, individual web pages were created to display current and future climate classifications, urban population, surface urban heat island metrics, and recommended tree species. Tree suggestions were derived from "Brother Cities" whose current climate conditions resemble the projected future climate of the target city.

This structure provides an intuitive way for users to explore city-specific adaptation strategies in response to climate change.

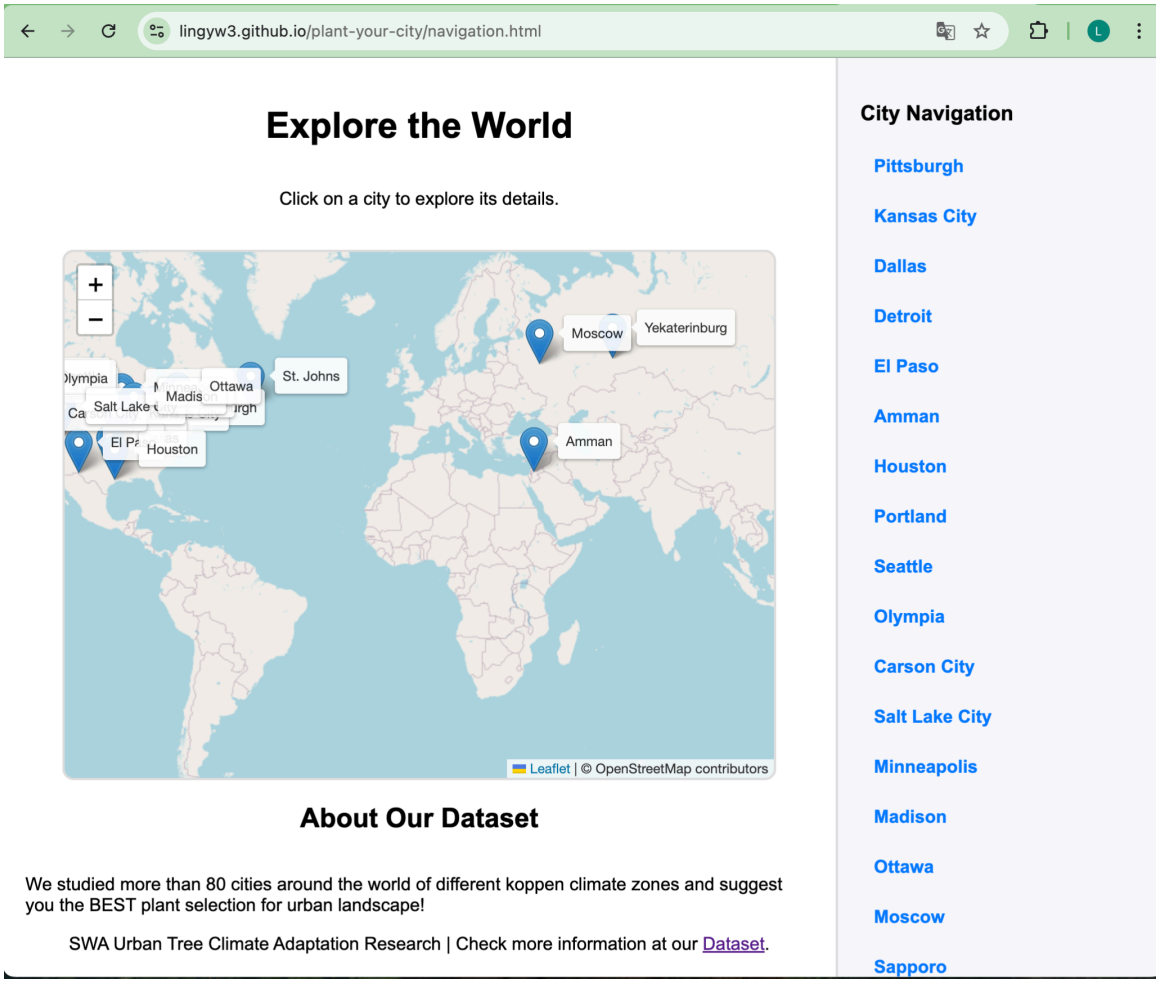


Figure 6. Screen capture of the *Plant-Your-City Explorer,* showcasing an interactive map

3.9 Final Tools Website

To integrate and present all project outputs cohesively, an interactive website was built using HTML, CSS, JavaScript (Leaflet.js), and Python.

This platform brings together all deliverables from the project—including global climate trend scenario maps, the climate zone vs. tree frequency table, the climate change story map, the *Plan Your City Explorer* pages, and the Methods of Adapting Urban Forestry Practices—into a unified public-facing interface.

The design emphasizes accessibility and usability, serving both public audiences and professionals in urban forestry, planning, and climate adaptation.

The source code and project materials can be accessed at the GitHub repository: https://github.com/lingyw3/plant-your-city. The interactive website is publicly available at: https://lingyw3.github.io/plant-your-city/.

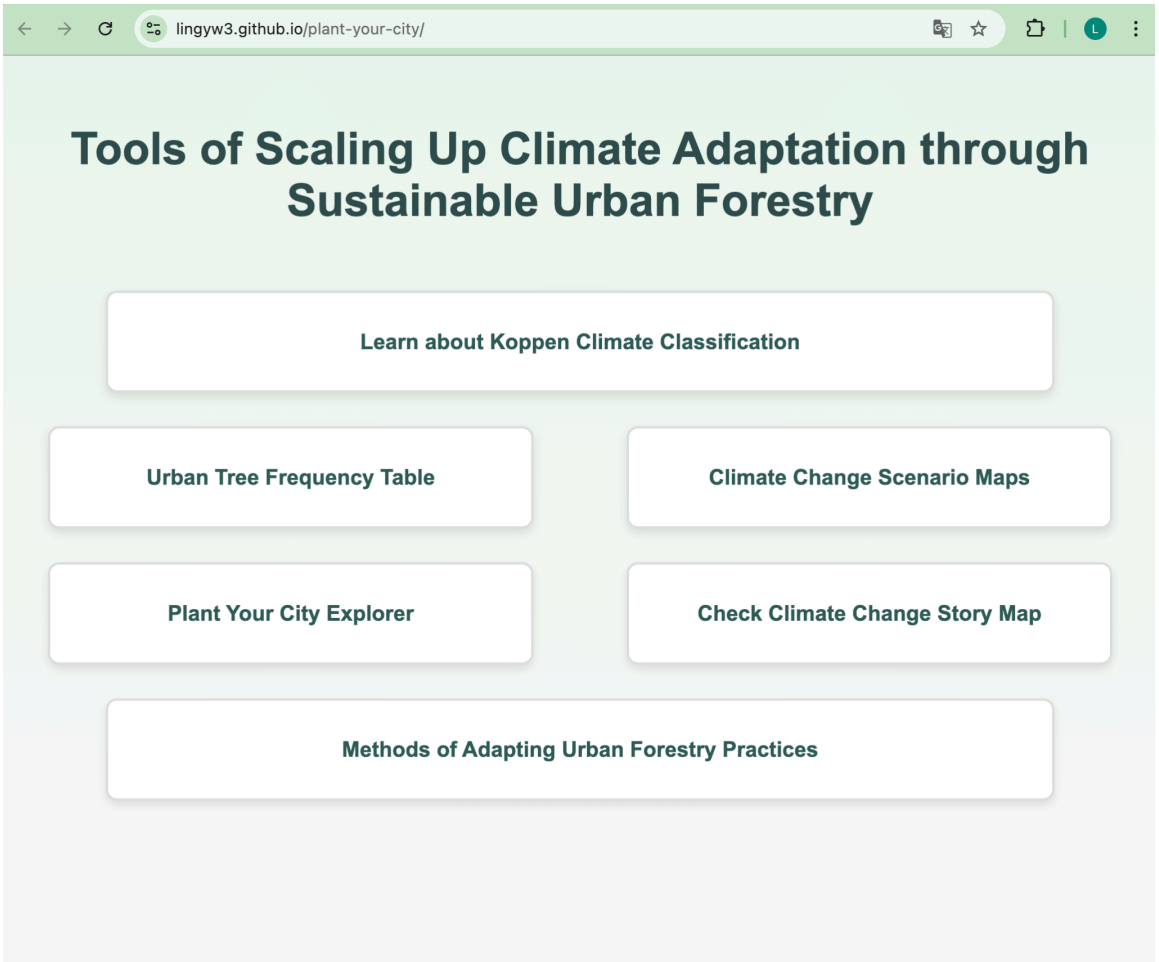


Figure 7. Screen capture of the Final Tools website, showcasing all the resources available to browse. A link to this website will be provided in the Appendix.

4. Results & Discussion

While this project is not necessarily based in *results,* but rather, a combination of other resources to create new tools, we did set out to look through our raw data to assess any trends, seeing which species were dominating which climate classifications, and especially if there were any commonalities between cities within the same subclassification. We found that most tree species appeared in Cfa (humid subtropical) with 87 species, followed by Dfb (cold humid continental) with 76 species, and Cfb (temperate oceanic) with 70 species. When grouped into large scale, temperate climates (C) supported the most tree species (269), followed by cold climates (D) with 141 species, tropical climates (A) with 110, and arid climates (B) with 92. These results indicate that temperate and humid zones are the most favorable for urban tree diversity. Climate-type pie charts and bar graphs further illustrated this concentration, with over 55% of total species distributed across Cfa, Dfb, and Cfb zones alone (Figure 8).

It is important to note that a lot of the geographic regions that will be experiencing the most change, specifically getting warmer, will be the climate subclassifications within the C- and D- types, which has major implications for how the distribution of species will change. These are currently the most diverse subclassifications; getting warmer may allow for even more species to be planted within these regions, but it may also mean that species that are currently planted here may no longer survive in the increasing temperatures.

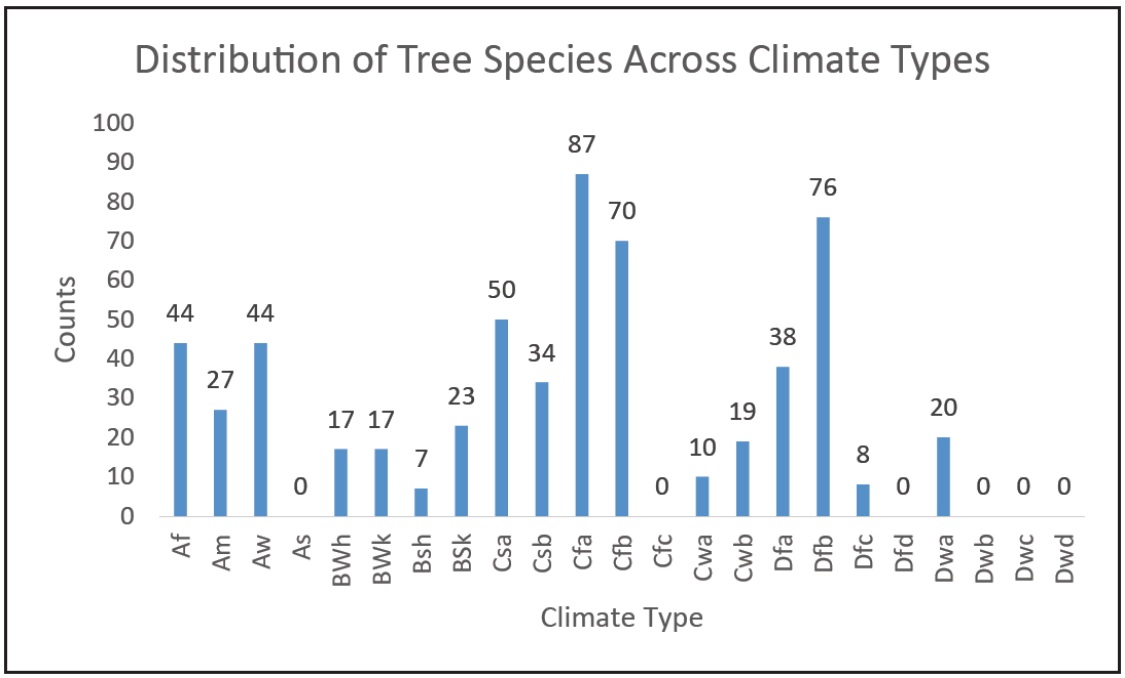


Figure 8. Column graph showing the distribution of the number of tree species across all subclimate types

Our analysis also identified the top 10 most climate-adaptable tree species, based on the number of different climate types in which each species occurs (Figure 9). *Platanus acerifolia* was the most adaptable, found in 8 climate types (e.g., Cfa, Cfb, Csa, Dfa, Dfb, Dwa), followed by *Acer negundo* and *Prunus cerasifera*, each found in 7 types. A frequency diagram further revealed the intensity of distribution, such as *Acer platanoides* occurring 12 times in Dfb and *Prunus cerasifera* appearing 6 times in Dfb and 3 times in Dfa. The breakdown of each species is shown in Figures 10a and 10b, identifying the climate types each of the 10 are found in.

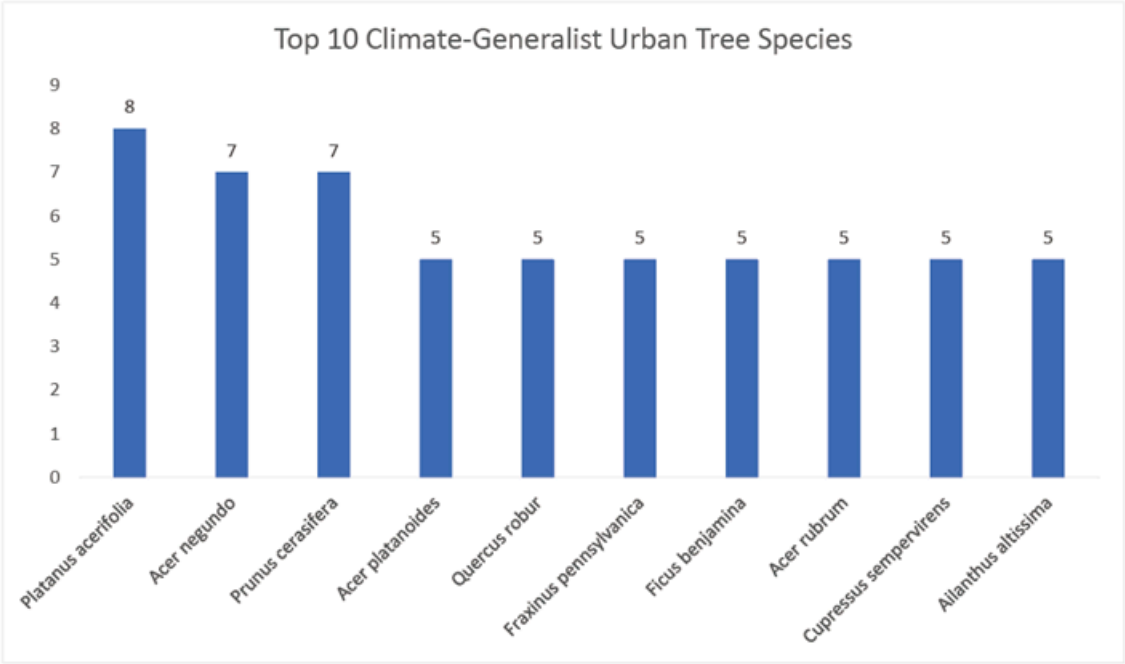
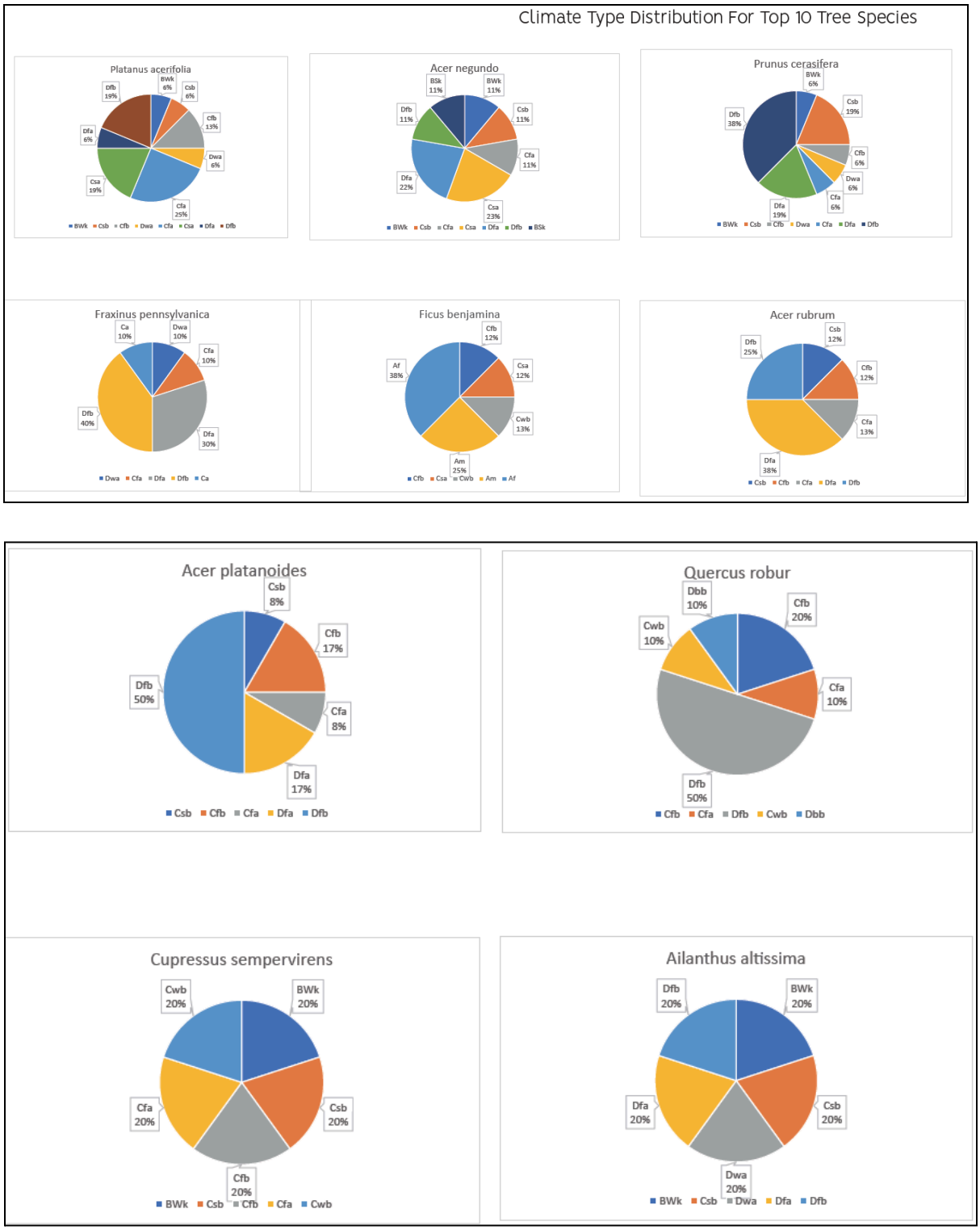


Figure 9. The top 10 climate generalist species according to our raw data; columns represent the number of climates each species is found in.

Identifying the top generalist species is important in having a solid foundation of trees that are known to be more climate resilient. It gives practicing entities a variety of species to begin planning with, and from there, they may be more inclined to research for more specialized species that are native to their geography or have some other characteristics that would benefit their city. These generalist species are also well-known and their resilience against climate change is validated in literature and real-world experiences. Since the species are quite general, they have already been planted in many cities around the world and continuing to plant these species can help to uphold a sense of familiarity within a city, rather than planting completely new species of trees.



Figures 10a and 10b. Pie charts of each of the 10 climate-generalist species broken down into the climates that each species is found in

In reaching out to various nurseries and municipalities, the responses were minimal. We reached out to approximately 10 nurseries and did not receive any replies to our inquiries. Any information that we have found about cultivars bred for climate change came directly from literature reviews. We received 4 responses out of 10 cities from Seattle,Washington; Phoenix, Arizona; Melbourne, Australia; and London, England. This is with the caveat that representatives from London responded initially to inform that they were gathering more information for our group, but never followed up. Melbourne and Phoenix both referred us to documents that could be found online. Seattle added in additional information of their changing practices, which included being in close contact with other municipalities in the Puget Sound region so that they all follow similar protocols and plant similar species across the region. At the time of communication, there was no set species list, but representatives mentioned that they were in the midst of creating a species list for that region. They also mentioned that the biggest infrastructure change will be in the watering regime: an increase in sapling watering from 3 years to 5 years. This means that young saplings will continue to follow a robust watering schedule for 5 years instead of stopping after 3 years.

The purpose of reaching out to specific entities was to see if any of them had practices in place that had not been reflected in the literature. The basis of the project as a whole is to help prepare tools for industry professionals to use within this realm, because currently, there are none. So understanding what's available in the literature is important, but it is even more important to know what is actively being done in cities and nurseries to prepare. Not receiving responses is not an indicator of lack of infrastructure changes, but it does make it more difficult to understand the big picture without input from those who are actively involved in making these different changes.

5. Future Research & Impact

The scope of the project was more than our team could feasibly accomplish within our 1.5 year timeline. The idea behind our work here was the partial first step towards a much larger project. While similar studies have been conducted on smaller scales, to our knowledge, this is the first study of its kind that has been done on a global scale, producing resources that can be used at a worldwide level, compared to specialized tools made for specific cities, states, or countries. What we completed during this time will serve as a good beginning resource for city planners, as well as a solid foundation for further projects and expansion. Specifically, further research is needed to expand species data across more cities globally, refine climate adaptation strategies, and deepen understanding of species-specific traits.

Our hope is for this research to continue, either through further SEAS capstone projects, or through independent measures with SWA. Because of the dynamic nature of climate change, the projected climate shifts that we've identified may not be the same in

25 years, in which case, new resources based off new projections may be necessary. That is to say, climate change should continue to be monitored through a lens which benefits urban planners and landscape architects, ensuring that cities worldwide can effectively adapt their urban forestry practices to a changing climate.

Long term, as this data is continually updated, so will our resources. The current resources that have come as a result of this project should be seen as prototypes. Fully-thought-out, usable, complete prototypes, but only in the beginning stages of their potential. SWA intends to host our resources on their website, while also giving the time, money, and resources necessary to make them more user-friendly, and eventually have them advertised and available to anyone worldwide. In doing so, it facilitates decision-making processes for urban planners, landscape architects, and policymakers aiming to build more resilient urban forests.

Acknowledgements

The project team expresses their gratitude to client Jonah Susskind, Director of Climate Strategy at SWA Group, and faculty advisors Mark Lindquist and Peter Reich from the University of Michigan's School for Environment and Sustainability for their combined time, expertise, guidance, and advice throughout the project timeline. Additionally, we would like to extend a special thank you to UM PhD candidate Xiaohao Yang for his coding help in the initial stages of this project.

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Appendix

Link to Final Tools Website: https://lingyw3.github.io/plant-your-city

Link to Final Tools GitHub Repository: https://github.com/lingyw3/plant-your-city

Link to the Species Frequency Distribution Table: https://lingyw3.github.io/plant-your-city/tree_species_frequency.html

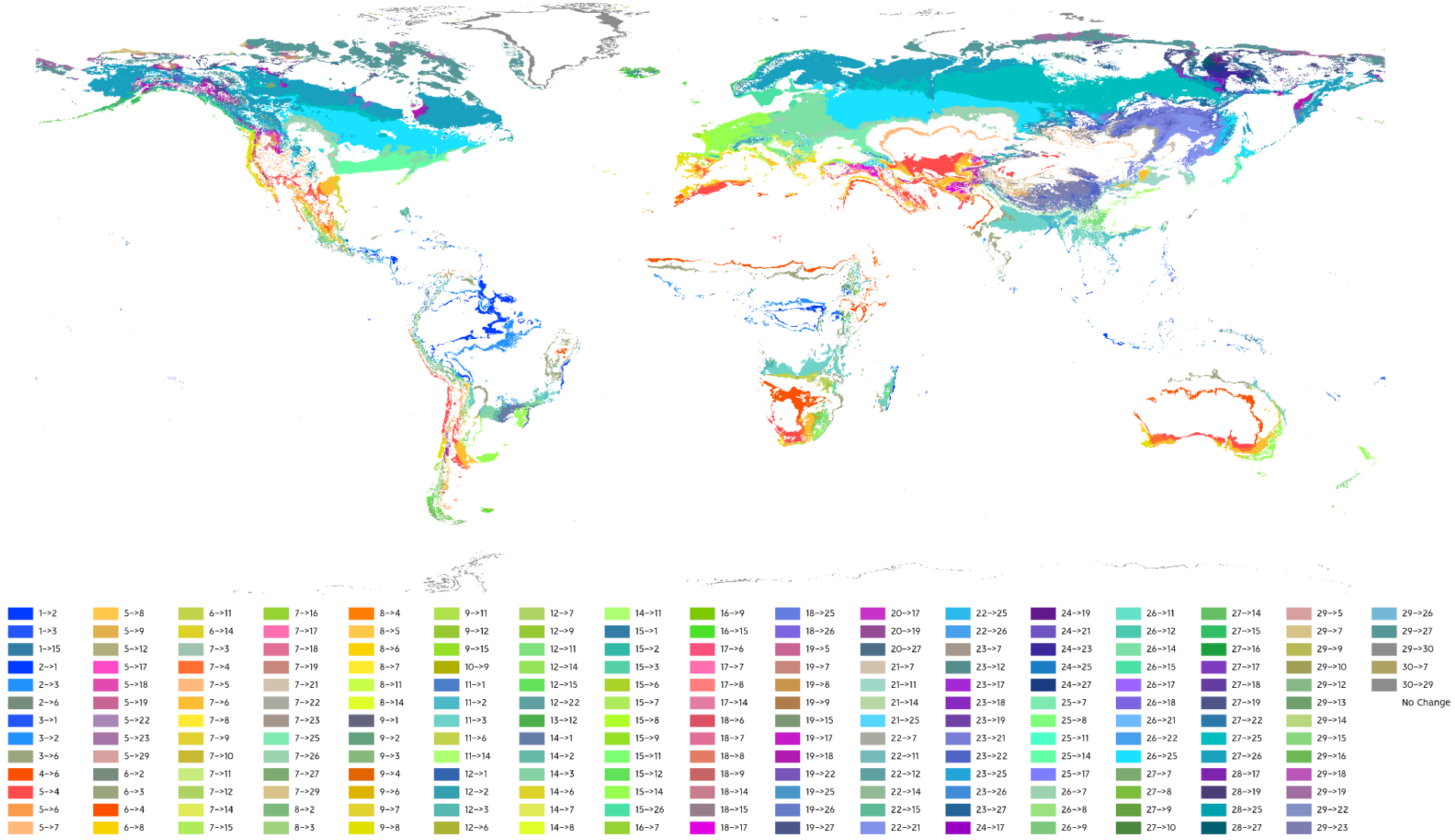


Figure A. Map illustrating all occurrences of Köppen-Geiger categorical changes

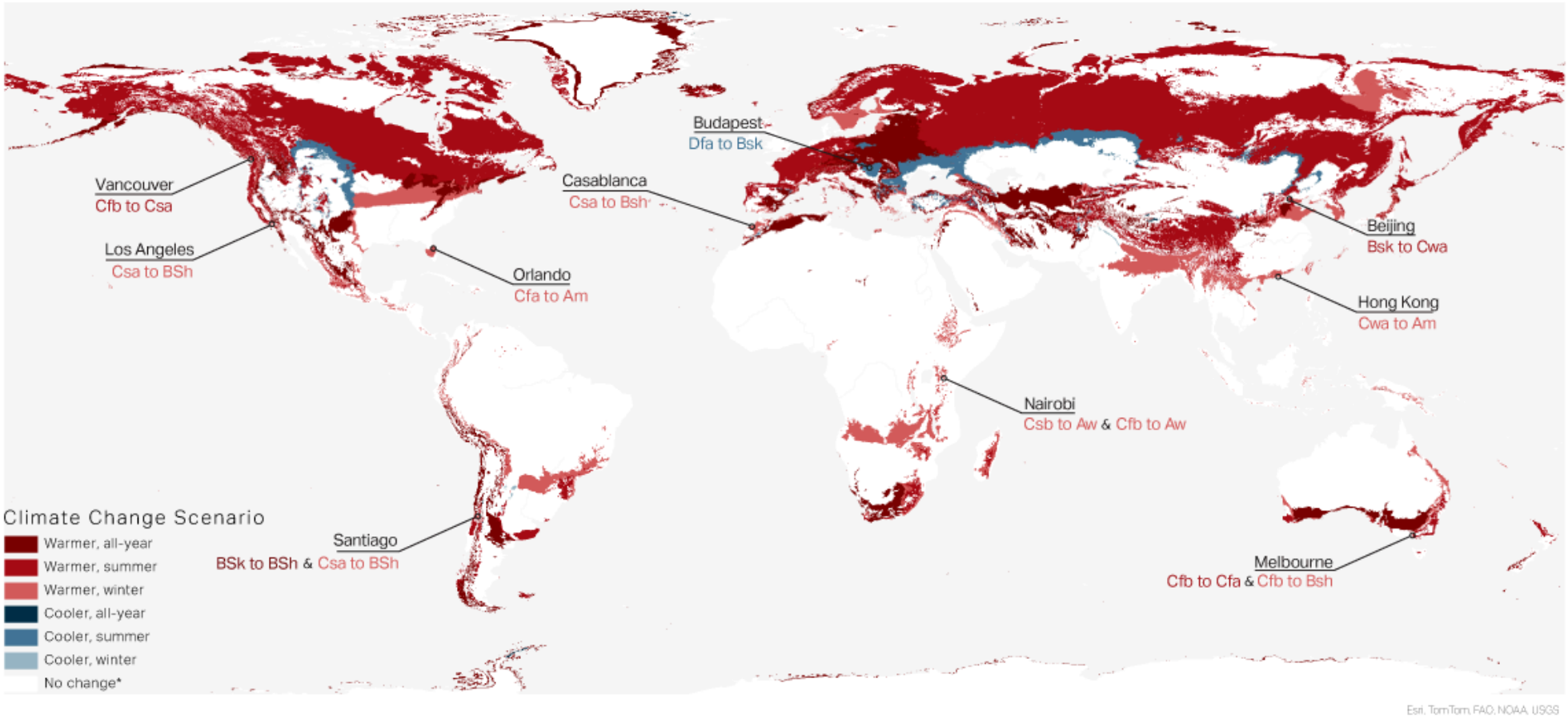


Figure B. Temperature Scenario Map

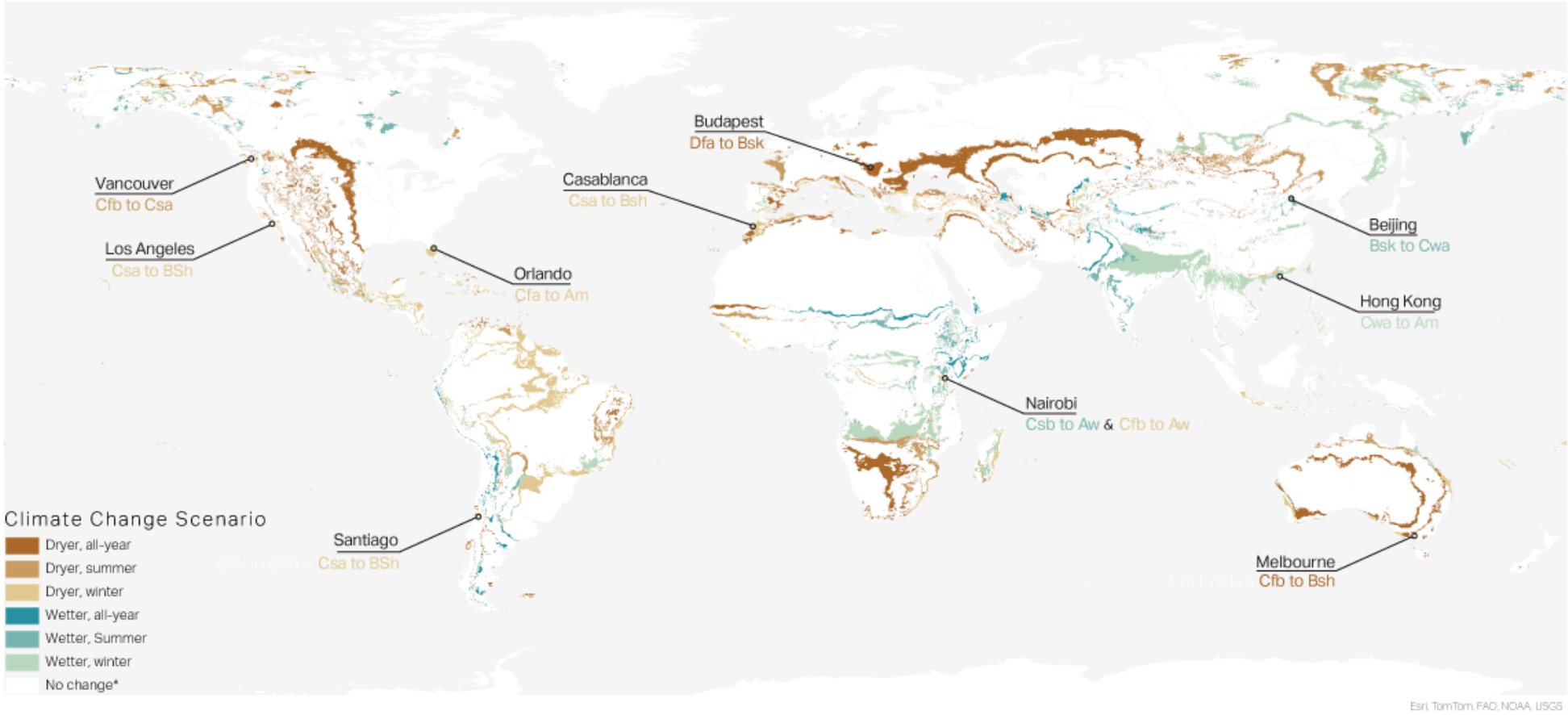


Figure C. Precipitation Scenario Map

Tree Species	Count	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Acer platanoides	24	Csb (Portland 1)	Csb (Seattle 1)	Cfb (Paris 4)	Cfb (Vancouver 3)	Cfb (London 2)	Dfa (Springfield 2)	Dfa (Coloumbus 6)	Dfa (Hartfort 2)	Dfb (Buffalo 1)	Dfb (Toronto 1 & 6)	Dfb (Ottawa 2)	Dfa (Montreal 2)	Dfb (Zurich 2)	Dfb (Bratislava 1)	Dfb (Vienna 1)	Dfb (Warsaw 1)
Quercus robur	10	Cwb (Johannesburg 4)	Cfb (Namur 2)	Cfb (London 4)	Dfb (Prague 1)	Dfb (Warsaw 4)	Dbb (Helsinki 6)	Dfb (Sofia 2)	Dfb (Belgrade 5)	Cfa (Tbilisi 5)	Dfb(Ukraine)						
Betula pendula	12	Csb (Seattle 3)	Cfb (London 6)	Dfb (Zurich 4)	Dfb (Bratislava 3)	Dfb (Warsaw 3)	Dfb (Stockholm 4)	Dfb (Helsinki 3)	Dfc (Reykjavik 3)	Dfc (Murmansk 1)	Cfb (Aukland 6)	Dfb (Sofia 10)	Dfb(Ukraine)				
Tilia cordata	9	Dfa (Columbus 7)	Dfa (Hartford 10)	Dfb (Buffalo 2)	Dfb (Toronto 5)	Dfb (Ottawa 7)	Dfa (Montreal 4)	Dfb (Bratislava 4)	Dfb (Prague 2)	Dfb (Warsaw 2)							
Fraxinus pennsylvanica	10	Dfa (Kansas City 9)	Dwa (Beijing 2)	Dfa (Chicago 7)	Dfb (Ottawa 9)	Dfa (Montreal 3)	Dfb (Winnipeg 1)	Dfb (Edmonton 2)	Cfa (Houston 9)	Ca (Buenos Aires 5)	Dfb (Calgary 2)						
Jacaranda mimosifolia	10	Cwb (Johannesburg 2)	Cwb (Mexico City 5)	Cwb (Morelia 2)	Cfa (Sydney 6)	Csa (Lisbon 3)	Csa (Seville 5)	Csa (Adelaide 6)	Csa (Perth 4)	Cfa (Buenos Aires 2)	Csa(Lisbon)						
Ficus benjamina	8	Am (Medellin 1)	Cwb (Morelia 5)	Af (Jakarta 6)	Af (Kuala Lumpur 10)	Am (Lagos 8)	Af (Santo Domingo 4)	Csa (Cape Town 1)	Cfb (Bogota 10)								
Acer rubrum	8	Csb (Portland 3)	Dfa (Springfield 3)	Dfa (Coloumbus 1)	Dfa (Hartford 6)	Dfb (Buffalo 4)	Dfb (Ottawa 3)	Cfb (Vancouver 5)	Cfa (Philadelphia 2)								
Ginkgo biloba	7	Cfa (Kunming 9)	Dwa (Seoul 1)	Dwa (Beijing 4)	Cfa (Tokyo 1)	Cfa (Philadelphia 10)	Dfb (Sofia 8)	Dfb (Belgrade 10)									
Prunus cerasifera	8	BWk (Mendoza 10)	Csb (San Jose 9)	Csb (Oakland 6)	Dwa (Beijing 6)	Dfb (Warsaw 10)	Csb (Santiago 1)	Cfb (Vancouver 2)	Dfb (Belgrade 8)								
Prunus cerasifera	8	Dfa (Columbus 3)	Dfa (Hartford 7)	Dfb (Buffalo 8)	Dfb (Toronto 2)	Dfb (Ottawa 5)	Dfa (Montreal 5 & 8)	Cfa (Philadelphia 5)	Dfb (Belgrade 3)								
Platanus acerifolia	16	BWk (Mendoza 4)	Csb (San Jose 3)	Cfb (Paris 1)	Dwa (Beijing 5)	Cfa (Sydney 2)	Cfa (Tokyo 4)	Csa (Barcelona 3)	Dfa (Columbus 8)	Dfb (Prague 3)	Dfb (Oslo 2)	Csa (Australia	Cfa (Philadelphia	Cfb (Birmingh	Csa (Perth 1)	Cfa (Buenos Air	Dfb (Belgrade 4)
Fraxinus excelsior	10	BWk (Mendoza 2)	Cfa (Bologna 3)	Cfb (Namur 9)	Cfb (London 1)	Dfb (Zurich 9)	Dfb (Prague 4)	Dfb (Warsaw 6)	Cfb (Birmingham 4)	Dfb (Sofia 1)	Cfa (Tbilisi 6)						
Acer saccharinum	6	BSk (Shiraz 2)	Dfa (Springfield 7)	Dfb (Buffalo 1)	Dfb (Toronto 6)	Dfa (Montreal 1)	Dfb (Warsaw 3)										
Carpinus betulus	7	Cfa (Bologna 6)	Cfb (Namur 7)	Cfb (London 8)	Dfb (Zurich 1)	Cfb (Vancouver 5)	Cfb (Birmingham 10)	Dfb (Sarajevo 7)									
Picea pungens	6	Dfb (Toronto 3)	Dfb (Ottawa 6)	Dfa (Montreal 9)	Dfb (Vienna 7)	Dfb (Edmonton 3)	Dfb (Calgary 1)										
Acer negundo	9	BWk (Mendoza 7)	BSk (Tehran 1)	Csa (Mashhad 2)	Cfa (Bologna 9)	Dfa (Hartford 9)	Dfa (Chicago 2)	Dfb (Vienna 6)	Csa (Lisbon 5)	Csb (Santiago 4)							
Liquidambar styraciflua	5	Csb (San Jose 4)	Csb (Oakland 4)	Csb (Santiago 2)	Cfb (Bogota 5)	Cfa (Houston 3 & 7)											
Acer pseudoplatanus	5	Cfb (London 3)	Dfb (Zurich 8)	Dfb (Warsaw 7)	Cfb (Birmingham 3)	Dfb (Sofia 3)											
Ulmus americana	5	Dfa (Kansas City 3)	Dfa (Chicago 6)	Dfb (Winnipeg 2)	Dfb (Edmonton 1)	Cfb (Vancouver 10)											
Sophora japonica	5	Dwa (Beijing 1)	Cfa (Toykyo 9)	Csa (Seville 8)	Dfb (Sofia 6)	Dfb (Belgrade 1)											
Picea glauca	5	Dfa (Springfield 5)	Dfb (Ottawa 4)	Dfb (Viennna 8)	Dfb (Edmonton 4)	Dfb (Calgary 4)											
Sorbus aucuparia	5	Dfb (Stockholm 5)	Dfb (Helsinki 8)	Dfc (Reykjavik 1)	Dfc (Murmansk 2)	Cfb (Birmingham 7)											
Aesculus hippocastanum	8	Cfa (Bologna 4)	Cfb (Namur 3)	Dfb (Zurich 10)	Dfb (Vienna 2)	Dfb (Warsaw 8)	Bsk (Ankara 1)	Dfb (Belgrade 7)	Dfb(Sarajevo)								
Pterocarpus indicus	6	Af (Bandung 9)	Af (Singapore 2)	Af (Jakarta 2)	Af (Kuala Lumpur 1)	Am (Ho Chi Minh City 6)	Aw (Bangkok 1)										
Quercus rubra	5	Dfa (Springfield 6)	Dfa (Hartford 4)	Dfb (Toronto 4)	Dfb (Ottawa 10)	Cfa (Philadelphia 6)											
Cupressus sempervirens	5	Cwb (Mexico City 4)	Csb (San Jose 7)	Cfa (Bologna 10)	BWk (Amman 3)	Cfb (Bogota 7)											
Acer campestre	6	Cfa (Bologna 1)	Cfb (London 10)	Dfb (Buffalo 5)	Dfb (Zurich 5)	Dfb (Warsaw 9)	Cfb (Vancouver 9)										
Pyrus calleryana	5	Csb (San Jose 6)	Csb (Oakland 3)	Dfa (Coloumbus 2)	Csa (Adelaide 3)	Cfa (Philadelphia 4)											
Ailanthus altissima	4	BWk (Mendoza 9)	Dfa (Kansas City 2)	Dwa (Beijing 9)	Csb (Santiago 10)	Dfb (Sofia 5)											
Swietenia macrophylla	4	Af (Bandung 1)	Af (Singapore 5)	Af (Jakarta 1)	Aw (Bangkok 4)												
Ulmus parvifolia	4	Cwb (South Africa 3)	Cwb (Mexico City 9)	Cfa (Taipei 8)	BWh (Phoenix 4)												
Syringa reticulata	5	Dfa (Colombus 9)	Dfb (Buffalo 7)	Dfb (Toronto 7)	Dfb (Ottawa 8)	Cfa (Philadelphia 9)											
Mangifera indica	4	Am (Medellin 2)	Am (Lagos 10)	Aw (Accra 2)	Af (Santo Domingo 2)												
Acer saccharum	5	Dfa (Springfield 1)	Dfa (Colombus 4)	Dfa (Hartford 8)	Dfb (Ottawa 1)	Csb(Seattle)											
Platanus x hispanica	5	Cwb (Johannesburg 1)	Cfb (London 5)	Dfb (Zurich 3)	Dfb (Warsaw 5)	Dfb (Sofia 4)											
Lagerstroemia indica	4	Csb (San Jose 2)	Csb (Oakland 2)	Dwa (Seoul 4)	Csa (Adelaide 8)												
Delonix regia	5	Af (Bandung 8)	Cwa (Hong Kong 9)	BWh (Cairo 2)	Am (Logos 5)	Am (Ho Chi Minh City 9)											
Cocos nucifera	4	BSh (Merida 1)	Am (Lagos 7)	Aw (Accra 3)	Af (Santo Domingo 6)												
Cinnamomum camphora	3	Cfa (Taipei 1)	Cfa (Kunming 1)	Cfa (Tokyo 7)													
Pistacia chinensis	3	Csb (San Jose 1)	Csb (Oakland 8)	BWh (Las Vegas 7)													
Platanus orientalis	5	BSk (Shiraz 8)	Cfa (Kunming 4)	Csa (MAshhad 1)	Dwa (Seoul 9)	Csa(Athens)											
Roystonea regia	3	BSh (Merida 3)	Cfa (Taipei 7)	BWh (Cairo 10)	Am (Logos 2)												
Peltophorum pterocarpum	3	Af (Singapore 3)	Af (Kuala Lumpur 2)	Am (Ho Chi Minh City 4)													

Table 1. Screenshot of the Tree Species Climate-Type Table: This table is broken down by each species, with the total number of appearances in our data and each climate type it is found in, along with the number of cities it is found in