Climate Risk Analysis of Tucson Tree Species

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Abstract:

Trees can play a significant role in mitigating and adapting to global climate change, especially in urban environments. As such, urban greening initiatives are emerging at the forefront of community strategies for a changing climate. However, predicted increases in global temperature of 2.7-3.6 degrees Celsius by 2100 pose installation challenges for trees in an urban context (3,4). Therefore, it is increasingly important to evaluate tree climate adaptation to ensure they are selected based on potential to survive and thrive in both the current and projected future climate. The University of Arizona Campus Arboretum and the Tohono Chul Park, are living collections of arid-adapted trees, situated within an urban center in the Sonoran Desert. These gardens provide a wide array of tree species to evaluate for potential performance in projected climate scenarios. With the 2017 release of the Global Tree Search, a database of 60,000 known tree species observed globally, and the subsequent development of the Climate Assessment Tool by Botanic Gardens Conservation International (BGCI) in 2022, we determined to **evaluate climate ratings of 474 species in our collections under current and future predicted climate scenarios for Tucson, AZ including: "Current Climate" (based on climate data from 2020, which assumes a mean annual temperature (MAT) of 21°C)), an "Emissions Limited" (EL) scenario (SSP2/RCP4.5 which assumes a MAT of 23.6°C) and a "Business as Usual" (BU) scenario (SSP3/RCP7.0 which assumes a MAT of 26.5°C).** By comparing the taxa in two local arborescent plant collections with global observations of those species in regions around the world with a MAT equal to that in Tucson currently, and the MAT predicted for Tucson under the EL and BU scenarios, we generated a list of species with potential to be climate-adapted. We further refined the list to **select only species known to survive in climates with specific MATs with less than 500 mm of precipitation, as this is a constraint dictated by the Campus Arboretum's collection policy to support landscape water conservation**. The initial results highlight species with the greatest promise for performing well within Tucson's current/future climate, though they also reflect an overall decline in the collection's biodiversity with rising temperatures unless additional adapted species are identified and planted. A subset of the species analyzed were identified with potential to perform better in warmer climate scenarios including one species with potential to survive in all three climate scenarios. These findings inform curation decisions and sustainability of both arboreta collections and may be relevant for tree planting recommendations in the surrounding community. Future work will include ranking and recommending species for production and planting based on more precise temperature (high and low) thresholds and performance observed by urban forestry, and nursery practitioners.

Introduction:

Trees can support environmental adaptation and aid in climate change mitigation. **Mitigation** refers to direct action taken to prevent or decrease the emission of greenhouse gases, targeting specific causes and streamlining the transition to renewable energy, in turn alleviating the severity of climate change (9). Key mitigation strategies include afforestation (establishing forests on lands not previously forested), and reforestation (restoring forests lost to wildfires or human activities) (9). Both of these strategies are effective in reducing climate change as the growth of new trees restores carbon sinks previously lost, and constructs new ones to sequester atmospheric carbon that may continue to be produced (9).

Adaptation strategies involve adjusting to the impacts of changing climate, by minimizing the vulnerability of ecosystems, communities, and infrastructure to rising temperatures, extreme weather events, and sea-level rise (9). Trees are the cornerstone of adaptation, as they provide a natural infrastructure that regulates local climates, fortifies soil preventing erosion, and protects against flooding, essential in adapting coastal areas to rising sea levels and in reducing urban flooding inland (14,15,16). Additionally, urban greening, or planting trees in cities, not only improves air quality but also creates a cooling effect making cities more resilient to the urban heat island effect (14,15,16).

While there are many strategies for climate adaptation and mitigation, trees offer a low cost and accessible solution for both while also enhancing the overall social and economic quality of urban communities (14,15,16). A few examples of the environmental services trees contribute to cities include improving air quality, filtering out pollutants and particulate matter, while releasing oxygen as they photosynthesize (8,14,15). The shade trees cast can help to reduce energy consumption of nearby buildings, reducing GHG emissions and providing economic savings (14,15,16). Casting shade coupled with evapotranspiration allows urban trees to help regulate temperature, alleviating the urban heat island effect plaguing many cities today (14,15,16). On average, urban forests have been observed to have temperatures 2.9 degrees Fahrenheit lower than unforested urban environments (16). Tree roots stabilize soil, reduce erosion, filter pollutants, while also reducing stormwater runoff/flooding through absorption (8,14). A few economic benefits of urban trees include energy savings, flood-mitigation infrastructure, and increased property values (14,15,16). Trees also contribute social, cultural, and educational value in communities. Most enchantingly, trees do wonders for mental health, with even minimal exposure to greenspaces being shown to greatly reduce stress and enhance mental health (14,15,16). Additionally, trees accentuate the beauty of urban areas and cultivate inviting atmospheres for social gatherings, contributing to a greater sense of belonging for its inhabitants (8,14,15,16). Ultimately, trees are a natural resource that act as a multifaceted instrument in both preventing future change to climate, mending the damage already done, and supporting the needs of other living things as well as natural processes.

Collectively, the benefits trees provide are considered within the larger context of the whole ecosystem, as "**ecosystem services**". Ecosystems provide four distinct components to society: ***provisioning*** services (food, clean water, fuel, timber, and other goods), ***regulating*** services (climate, water, pollination, and disease regulation), ***supporting*** services (soil formation/nutrient cycling), and ***cultural*** services (educational, aesthetic, tourism, recreation, and cultural heritage values) (8). Given the compounding benefits trees provide to the triple bottom line, and both the quantity and breadth of benefits urban trees provide in cities, the importance of planting, preserving and sustainably managing and integrating in climate action plans trees has never been more clear (16).

Unfortunately, in the next 50 years, plants growing in urban landscapes and botanic gardens will be subjected to temperatures never experienced before (2,6,7). Projected increases in global mean annual temperature (MAT) of 2.7 to 3.6 degrees Celsius by 2100 and additional challenges presented by urban environments, the selection of trees for urban sites must be thoughtfully considered (3,4). In recognition of these facts, the **Botanic Garden Conservation International** (BGCI) set out to create a **climate assessment tool** (CAT) useful in the evaluation of tree species for various climate scenarios detailed in the **Intergovernmental Panel on Climate Change's (IPCC) 6th assessment report**. Organizations across the globe have already begun the work of analyzing and cataloging species of trees and pairing their suitability for a specified location given predictive climate models.

Information about Global tree search, Climate Change Alliance of Botanic Gardens, and background to the CAT we used.

Botanic Gardens and Arboreta house diverse collections of plants that not only support scientific and horticultural research of plants in an urban context, but also provide a platform to engage the non-scientific community, by providing education and appreciation of natural splendor. With the warming climate posing unique threats to urban greenspaces such as botanic gardens, the leaders of many horticultural organizations across the globe convened for the botanical community's first Climate Change Summit at the Royal Botanic Gardens Melbourne in 2018 (6,7). There, ambassadors from 13 international botanic institutions instated the Climate Change Alliance of Botanic Gardens, with the current membership composed of over 65 botanical institutions and growing (6,7). The Alliance has been instrumental in the enactment of positive reform in governments, hosted numerous forums/workshops that guide effective climate responses and plant conservation, and has provided countless other botanical tools (6). Membership in the Alliance is free and offers botanical organizations the opportunity to access data from botanic institutions across the globe, enabling them to better protect and understand the challenges being faced through information sharing (6,7).

Many notable institutions have pledged their support, including the Botanic Gardens Conservation International (BGCI), creators of The Global Tree Search, a database that encapsulates all known species of tree and their distribution on a country-level basis (2,6). Creation of this database was an undertaking of two years, being completed by the BGCI in 2017. The BGCI hosts the Climate Risk Assessment tool used in this project, with the Global Tree Search as one of its supporting databases (2,6). In collaboration with the Royal Botanic Gardens Victoria, BGCI, and the University of Tasmania, the Alliance developed the first stage of the Climate Risk Assessment Tool that can help manage botanical collections (2,6). The first stage of Climate Risk Assessment Tool is centered around 20,000 tree and arborescent species housed in botanic gardens around the world, and the tool has been imbedded into the BGCI's Plant Search database (2,6). This tool will provide further support for botanical institutions to adapt their collections and quantify the impact of climate change on their specimens (2,6). The BGCI's Climate Risk Assessment tool's analyses of different arborescent species' performance is based on the predictive climate models detailed in the Intergovernmental Panel on Climate Change's 6th assessment report.

Climate change facts and predictions. Models used or referenced in the climate assessment tool (CAT).

The Intergovernmental Panel on Climate Change (IPCC) is an international body responsible for assessing current scientific literature and informing science-based policies and actions aimed at combatting global anthropogenic climate change. The IPCC was established by the World Meteorological Organization and the United Nations Environment Program in 1988, and publishes a series of reports covering the scientific, technical, and socio-economic aspects of climate change (10). Nearly a decade since its last publication, the IPCC began releasing its 6th Assessment Report in August of 2021 (3). The findings predict that as early as 2030 a global increase in temperature of 1.5 degrees Celsius could be likely, ten years earlier than expected, highlighting a much more rapid warming event than previously thought (3).

The IPCC's 6th Assessment report establishes a multi-view forecast centered around 5 possible scenarios for the future climate dependent on the degree at which society employs preventative strategies and the severity of warming (3). The climate scenarios integrated within the CAT are a Current, Emissions Limited, and Business-as-Usual scenario. The Current Climate Scenario directly uses climate data from 2020, while the Emissions Limited scenario and Business-as-Usual scenario are based on 2 out of the 5 models developed by the IPCC (SSP2/RCP4.5 and SSP3/RCP7.0 models, respectively). Despite the varying differences amongst each scenario's warming rate and mitigation techniques, warming will exceed past the 1.5°C mark in the next two decades (3). This widely accepted and inevitable increase of global temperature in the short term is one of the unfortunate consequences of past inaction, however the intensity of present and future efforts to employ mitigation tactics will determine whether the future climate curve is lowered. The BGCI Tree Risk Assessment tool allows users to evaluate tree species suited for their location given three climate scenarios. Each scenario's evaluation is extrapolated from the predictive climate-data obtained through the IPCC, and are as follows:

Current Climate:

The BGCI's "Current" Scenario uses direct climate data recorded from 2020.

Emissions Limited Climate Scenario:

The BGCI's "Emissions Limited" scenario is based on the SSP2 or RCP4.5 emission prediction developed by the IPCC (1). It is based on the predictive climate of 2050, with added consideration that measures have been put in place to curb global emissions (1). It is outlined as having moderate greenhouse gas emissions, with dwindling emissions around 2050, but net-zero is not accomplished until after 2100 (3,4). Global temperatures increase by 2.7 degrees Celsius by 2100 (3,4).

Business as Usual Climate Scenario:

The BGCI's "Business as Usual" scenario is based on the SSP3 or RCP7.0 emission prediction developed by the IPCC (1). It is based on the predictive climate of 2090, with a consideration that no measures have been put in place to limit emissions (1). It is outlined as having moderate to high greenhouse gas emissions, with no reduction in emissions, and steady increases toward the end of the century. It estimates that the total amount of carbon dioxide in the atmosphere today will be doubled by 2100, with global temperatures increasing by 3.6 degrees Celsius by 2100 (3,4).

Information on the Campus Arboretum history and collection relating to trees for desert climates.

The University of Arizona Campus Arboretum was established in 2002 as a living collection of arid adapted trees and shrubs from around the world integrated into the roughly 400 acres of the main campus. The Campus Arboretum's mission is to promote stewardship and conservation of urban trees for arid climates. In partnership with Tucson **Tohono Chul Garden**, who completed a full tree inventory in 2022, the combined set of tree species to consider provides a rich pool of potential climate ready trees for a variety of climate scenarios. Further, the location of these collections in the American southwest where climate impacts are heightened, offers great potential to shed light on the possible upper climate limits of the world's tree species.

Campus Arboretum Collections policy summary

The mission of the Campus Arboretum is the proper preservation, optimization, and stewardship of the living collection of plants on the University of Arizona's grounds (5). The plants incorporated into the collection were selected with emphasis on their educational/research potential, historic, environmental, economic, and aesthetic value, as well as their ability to survive and thrive in an urban arid environment (5). This mission has guided the curation of a collection of plants that provide the greatest benefit to the University and surrounding community, and the Collections Policy ensures that further plants acquired adhere to these parameters (5). The Collections policy's main focus is to guide the proper development and management of the Campus Arboretum's living collection through thoughtful consideration of the Arboretum's mission and the resources available to which the acquisition of appropriate specimens can be performed (5). The policy outlines arid/semi-arid conditions as those that receive less than 250mm and 500mm respectively (5). Concerning temperature, acquisitions (once mature) should be capable of tolerating minimum temperatures of -5 to -8 degrees Celsius for short periods, and prolonged periods of 42 degrees Celsius (5). In addition to mean annual temperature adaptation, a plant's water needs should also be considered as water use closely relates to heat tolerance. When a tree is subjected to increased heat, transpiration provides cooling necessary to sustain metabolism. In an urban environment, this requires supplemental irrigation which has additional impacts to overall sustainability. As sustainability is the overarching goal in urban forestry programs, heat tolerance should not be the sole criteria for selecting promising tree candidates, their water-use should also be considered. For this reason, the Campus Arboretum's Collection Policy also defines thresholds for both temperature and annual precipitation. The environmental criteria of the collection policy states that plants selected for installation on campus should be considered for their adaptation to arid/semi-arid conditions unless significant educational value warrants an exception (5). The collections policy also acknowledges that certain microclimates found within the university can warrant the addition of a specimen that would not survive the typical weather of Tucson, Arizona (5).

Question addressed in this project.

The primary purpose of this project is to evaluate the current and future climate adaptation of tree species growing in two Tucson plant collections. Using the BGCI Climate Risk Assessment tool, an analysis was performed on the existing taxa housed in Tucson collections, to assess and rank tree species' potential for various climate scenarios. **Analysis of the Tucson collections' tree inventories resulted in a list of trees we can tentatively point to with promise to perform well under current and/or future climate in Tucson, AZ.** This data will append the arboreta's collections policies, inform succession plans, promote sustainability, and resource conservation, and identify species in greatest need of protection, ex situ preservation of germplasm, or other conservation measures. This assessment will also inform planting strategies that maximize the benefits of trees in terms of their educational value, and environmental services in a hotter and drier climate.

Additionally, to determine suitability for a hotter future climate, we will **consider both mean annual temperature adaptation and irrigation needs**. As such, the evaluation will point to plant species suited for hotter climates, but which are also water-wise recommendations.

Both the Tohono Chul Gardens and the University of Arizona Campus Arboretum aim to promote science-based practices that can change attitudes and behaviors around urban landscape sustainability. These shared goals connect directly with production choices of regional nurseries, which is largely influenced by market demand, landscaping trends and consumer preferences (11). Consumer preferences are mostly shaped by aesthetic appeal of plants, with the color of the foliage or flowers being the most influential quality (11). Many nurseries produce stock generally believed to be suited for regional climate including regional temperature and precipitation (12). **However, with significant drought plaguing the southwest, science-based recommendations for nursery producers are increasingly important.** Arizona, along with many of the states that rely on the Colorado River for a portion of their water supply, are facing significant reductions in their allotment (13). Arizona alone saw a 21% reduction in its share in 2023 (13). As a secondary aim of this project, the list of optimal species for current and future climate will be publicly shared with community members (consumers) and with tree nursery producers to influence both supply and demand for climate ready trees.

Materials and Methods

Data available and processing, and use of the CAT

The subjects used for this project came from a taxa list of 830 tree and arborescent plant species which are currently or have been housed in either the University of Arizona Arboretum collection, and an additional 742 taxa growing in the Tohono Chul Botanical Gardens in Tucson, Arizona. Both institutions' taxa lists were first merged, sorted to remove any duplicate species entries, and further refined to include only species for which the BGCI's Climate Risk Assessment Tool (CAT) currently has available climate data. After merging and filtering the data set, a list of 474 different species of tree and arborescent plants was generated and then processed using the CAT to obtain species-specific climate risk scores.

The results populated for each species' climate suitability is based on Mean Annual Temperature (MAT) of the selected geographic location compared to the MAT observed in the natural range of the selected species (1). Within the parameters of the BGCI'S CAT, MAT is assumed to be the most significant variable influencing a species' performance in an urban environment, since other climate variables like precipitation can be manipulated by human activities such as irrigation or improved soil drainage (1). The data populated by the tool also provides the Mean Annual Precipitation of each species in its natural range, with this additional information, the results were further refined to include consideration of limited precipitation or irrigation inputs, per the University of Arizona's Collections Policy outlined in section IV. The choice to center climate analysis on temperature is a straightforward approach, as temperature is a climate variable that is far more unmanageable, especially in an urban environment (1). Minimum temperature can also be a principal climate concern, especially in colder regions**.** While, a tree's survival is largely determined by whether it can handle the instantaneous temperature extremes of a given climate, (MAT may be obtained by varying high and low instantaneous temperatures), we acknowledged that while MAT is not precise enough to predict species performance, it is a useful initial variable for sorting and ranking our collections' overall potential for performance in the response to climate. (Future work will include additional evaluation of species high and low temperature threshold and consideration of practitioners).

The BGCI CAT assigns each species a value of 0-11 based on the frequency with which a species is observed in the (near edge, shoulder, or middle) of its natural or urban range under three climate scenarios (1). For this project, we sought to identify species with a **ranking of 11, indicating they would be in the middle of their natural range in the center of Tucson** proper (approximate location of the UArizona Campus Arboretum). This parameter was selected for its potential to identify a broader list of candidate species that could suit not only the natural areas around Tucson, but also for the variety of microclimates available in an urban context. Further, identifying which of our species have been observed in other urban datasets, introduces many potential factors not explicitly accounted for such as microclimate, location in controlled environments, or supplemental irrigation provided. Consequently, after the list of 474 species was processed by CAT under 3 climate scenarios (current, emissions limited, business as usual), those species that received a ranking of 11 were isolated for further consideration.

Climate Rating System for the BGCI Climate Risk Assessment Tool

0-Not known and not likely
1-Not known but possible
2-Not known but likely
3-Near edge of botanical garden range
4-Near edge of urban range
5-Near edge of natural range
6-Shoulder of botanical garden range
7-Shoulder of urban range
8-Shoulder of natural range
9-Middle of botanical garden range
10-Middle of urban range
11-Middle of natural range

In addition to the climate rating, the CAT also provides a variety of information in table form for each evaluation set. The table includes the following column headers:

Projected Temperature in degrees Celsius (Column B): denotes the projected temperature of a specific geographical location given the selected climate predictive model of the CAT (Current, Emissions Limited, Business as Usual.

Climate Rating (Column C): a sliding scale from 0-11 designed by the BGCI to categorize taxa based on whether when subjected to the Projected Temperature in degrees Celsius (Column B) they would be experiencing temperatures characteristic of the middle, shoulder, or near-edge, of what they would experience in their natural, urban, or botanical garden range.

Mean Annual Temperature (MAT) in degrees Celsius (Column D): denotes the mean annual temperature that a given taxon typically experiences in its natural range. (17)

Mean Hottest Month (MHM) in degrees Celsius (Column E): denotes the mean maximum monthly temperature observed over a span of years that a given taxon typically experiences in its natural range. (17)

Mean Coldest Quarter (MCQ) in degrees Celsius (Column F): denotes the mean quarterly temperature of the coldest quarter that a given taxon typically experiences in its natural range. (17)

Mean Annual Precipitation (MAP) in mm/year (Column G): denotes the mean annual precipitation that a given taxon typically needs/receives in its natural range. (17)

Mean Driest Quarter (MDQ) in mm/qtr. (Column H): denotes the mean quarterly precipitation of the lowest precipitative quarter that a give taxon typically experiences in its natural range. (17)

Based on average precipitation information provided, we were able to further refine our results by sorting based on annual water needs. Species were categorized into three groups: less than 500mm, between 501-750mm, and over 751mm.

Results*:

Given the geographic location of Tucson Arizona, under the Current Climate Scenario the mean annual temperature is 21 degrees Celsius (69.8 degrees Fahrenheit), with a maximum temperature of the hottest month as 38.2 degrees Celsius (100.8), and minimum temperature of the coldest month as 12.2 degrees Celsius (54.9 degrees Fahrenheit). The annual precipitation is 307mm per year, and the precipitation for the driest quarter is 20mm.

Species with Climate Rating 11 for Climate Scenario 1 (MAT 21°C) sorted by annual water needs.

This list is composed of taxa which have been observed in the middle of the natural range at the mean annual temperature (MAT) for the Current Climate Scenario of Tucson Arizona, 21 degrees Celsius. They are further divided based on their mean annual precipitation (MAP) as follows:

Green: Taxa highlighted in green are observed to have a MAP of less than **500mm** in their natural range.
Yellow: Taxa highlighted in yellow are observed with MAP needs of **501mm and 750mm** in their natural range.
Red: Taxa highlighted in red are observed with MAP needs **>751mm** in their natural range.

Taxon	MAT, °C	MHM , °C	MCQ, °C	MAP, mm/year	MDQ, mm/qtr
Pleradenophora bilocularis	21.7	18.6	7.7	115.0	3.0
Psorothamnus spinosus	20.9	28.8	9.3	168.8	7.8
Condalia globosa	21.6	28.4	10.6	173.5	6.4
Yucca valida	20.1	25.1	11	176.0	6.8
Prosopis pubescens	19.7	30.2	8.6	181.9	10.6
Prosopis palmeri	21.8	27.8	11.6	186.4	4.5
Parkinsonia florida	20.3	24.3	7.7	207.5	10.8
Vallesia laciniata	20.2	26.9	10.2	212.3	7.3
Pachycormus discolor	18.1	24.3	9	221.3	25.8
Olneya tesota	20.8	30.4	9.9	221.6	9.6
Stenocereus gummosus	19.6	24.5	10.8	224.0	7.6
Senegalia greggii	18.9	27	8.6	226.8	10.4
Bursera hindsiana	19.5	24.6	9.4	228.9	18.8
Jatropha cinerea	20.9	24.6	11.4	233.3	7.5
Parkinsonia microphylla	20.1	24.6	7.7	239.3	14.2
Maytenus phyllanthoides	22.3	23.2	10.1	251.7	7.8
Pachycereus pringlei	18.9	24.3	8.8	261.1	32.9
Fouquieria diguetii	19.8	24.1	10	272.5	33.0
Prosopis velutina	20	30.1	9.3	283.4	25.1
Acacia aneura	20.1	28.4	10	290.0	39.2
Acacia craspedocarpa	20.1	26.7	9.4	290.6	35.4
Bursera microphylla	19.9	25.1	8.8	291.4	30.4
Acacia jennerae	18	24.6	8.3	294.1	48.1
Bursera laxiflora	22.9	28.1	11.5	296.0	8.3
Acacia stenophylla	19.2	27.6	9.4	298.2	30.8
Fouquieria splendens	18.6	28.2	7.6	309.7	36.1
Stenocereus thurberi	20.1	26.1	9.3	317.6	35.3
Parkinsonia praecox	21.7	27.9	11	317.9	13.0
Carnegiea gigantea	19.4	29	8.2	319.4	34.2
Vachellia erioloba	19.5	21.5	8.2	320.0	33.0
Acacia brachystachya	19.9	25	9.1	321.3	59.0
Acacia cana	19.8	25.8	9.1	321.4	58.3
Acacia victoriae	17.8	24.2	8.3	334.5	56.0
Populus brandegeei	19.6	24.9	10.7	337.1	4.0
Cylindropuntia fulgida	20.6	26.2	8.9	339.3	28.3
Myrospermum sousanum	20.2	25.3	8.6	348.3	31.0
Brahea armata	17.7	25.4	9.4	351.0	24.4
Vachellia rigidula	20.4	23.7	7.6	352.5	48.8
Acacia cambagei	20.6	25.6	9.7	359.4	51.5
Erythrostemon mexicanus	20.6	22.6	8.1	363.3	44.2
Lysiloma watsonii	20.3	29.8	10.2	375.6	19.4
Abutilon incanum	21.8	26.2	10.7	381.0	42.0
Prosopis alba	18.7	26.8	10.4	381.7	20.8
Prosopis chilensis	18.5	26.5	9.7	381.9	20.6
Ziziphus spina-christi	23.7	27.6	13	381.9	22.4
Washingtonia filifera	18.2	26.9	8.6	382.1	46.5
Vachellia farnesiana	20.8	22.8	9	382.8	21.7
Havardia mexicana	21	28.1	10.6	389.3	16.6
Vachellia tortilis	21.4	25.2	11.2	395.0	29.9
Phoenix dactylifera	19.7	26.1	9.7	398.7	40.3
Senegalia occidentalis	21.3	24.6	8	401.8	48.5
Senegalia berlandieri	20	26	9.6	403.6	44.9
Vallesia glabra	23	28.5	14.3	408.1	14.0
Senegalia crassifolia	18.3	23.4	8.2	412.3	59.6
Vachellia constricta	18.9	24.7	9.4	414.6	31.3
Jatropha dioica	20.3	26.8	12.4	427.6	21.1
Brahea brandegeei	19.2	24.5	11	431.3	15.2
Fraxinus greggii	17.8	23.9	8	434.1	53.6
Neoraimondia herzogiana	17.7	20.4	9.3	436.8	41.5
Jatropha cordata	22.5	27.5	12.1	438.5	8.4
Coursetia glandulosa	22.7	27.8	12.1	441.5	14.0
Acacia salicina	17.9	24.7	9.1	444.1	75.0
Fouquieria purpusii	22.2	26.2	12.8	445.8	38.3
Celtis pallida	20.9	27.6	11.9	448.1	27.3
Neobuxbaumia polylopha	17.6	22.2	9	451.8	45.9
Havardia pallens	21.4	25.1	11	453.3	35.5
Prosopis laevigata	20.4	26	13.3	454.6	17.8
Mariosousa millefolia	17.7	25.3	6.5	455.9	53.1
Bauhinia macranthera	19.7	23.8	10.1	458.3	30.3
Yucca rostrata	17.3	25.9	8.4	461.4	46.0
Fouquieria formosa	20.1	23.5	12.5	468.8	13.8
Yucca grandiflora	19.9	27.5	9.5	469.1	22.5
Fouquieria fasciculata	19.3	23.6	10.7	473.4	49.6
Bauhinia lunarioides	20.5	28.2	9.7	474.3	59.9
Sabal uresana	19.8	24.7	8.9	479.5	48.8
Prosopis nigra	19.3	26.1	9.8	483.2	41.8
Acacia harpophylla	19.1	24.4	9.1	495.3	78.8
Ebenopsis ebano	22.4	28	11.7	496.2	42.2
Senegalia galpinii	18.6	23	9.4	500.5	30.0

Taxon	MAT, °C	MHM , °C	MCQ, °C	MAP, mm/year	MDQ, mm/qtr
Manihot caudata	19.7	24.8	11.5	510.5	10.8
Senegalia wrightii	18.6	20.6	6	510.5	87.5
Bursera fagaroides	18.3	20.2	7.3	518.7	45.0
Callaeum macropterum	20.4	24.4	9.4	519.0	40.9
Dombeya rotundifolia	18.3	21.6	10	524.3	30.5
Ipomoea arborescens	20.9	24.1	12.5	529.4	33.8
Nolina matapensis	18.1	25.2	9.3	533.5	20.4
Cordia boissieri	21.5	27.3	11.6	537.3	44.4
Stetsonia coryne	20.1	23.3	10.3	540.4	48.0
Aloe marlothii	17.4	21.2	8.5	544.0	46.0
Lysiphyllum carronii	20.8	23.8	10.8	545.1	73.0
Carissa macrocarpa	18.8	22.9	10.4	548.4	62.1
Yucca treculeana	19.9	24.6	9.3	549.8	76.3
Brachychiton rupestris	18.3	23.8	9.5	550.6	83.8
Ficus petiolaris	20.1	24.3	10.3	552.9	35.1
Ziziphus mucronata	21	25.5	13.2	571.0	27.3
Quercus canbyi	18.3	25.3	8.8	580.6	81.0
Senegalia caffra	21.8	20.2	9.5	588.2	58.3
Phanera variegata	21.7	16.3	8	591.5	4.5
Dovyalis caffra	17.6	20.7	9.8	593.5	65.5
Kalanchoe beharensis	19.6	23.2	11.2	593.7	42.7
Vachellia kirkii	20.7	19.5	12.3	601.0	31.3
Casimiroa edulis	18.2	23.6	11.6	605.5	31.4
Euphorbia trigona	19.6	20	7.4	606.0	47.7
Vachellia xanthophloea	20	23.4	12.5	607.9	36.5
Ehretia anacua	20.9	27.1	11.2	612.9	79.0
Vachellia aroma	18.8	23.3	9	619.1	75.8
Melaleuca viminalis	18.8	22.1	10	628.3	73.8
Bolusanthus speciosus	20.7	23.1	12.1	628.4	73.6
Vachellia pennatula	19	20.1	7.9	632.2	63.2
Euphorbia ingens	17.5	21.4	9.8	637.7	40.4
Libidibia paraguariensis	20.9	24.1	11.1	646.6	73.4
Cereus hildmannianus	18.3	21.8	9.9	647.5	84.5
Phoenix pusilla	23	20.4	12.4	652.0	93.0
Vachellia gerrardii	19.3	22.1	10.9	678.3	30.4
Yucca aloifolia	16.6	23.9	8.4	710.2	90.2
Euphorbia tirucalli	19.8	23.7	11.9	728.9	45.4
Acaciella angustissima	19.5	23.6	11.3	734.4	33.5
Brahea calcarea	17.9	21.6	10.9	734.8	50.0

Taxon	MAT, °C	MHM , °C	MCQ, °C	MAP, mm/year	MDQ, mm/qtr
Phoenix reclinata	21.4	23.7	13.4	755.4	68.4
Tecoma stans	20.6	24.6	13	793.0	50.1
Senna spectabilis	20.2	23.7	12.8	798.7	65.3
Hibiscus rosa-sinensis	20.4	22.8	9.8	812.1	56.4
Pinus roxburghii	17	23.2	8.4	813.6	66.2
Erythrina abyssinica	19.9	22.6	13.8	823.9	39.4
Cereus repandus	23	25.1	13.8	824.7	79.3
Anadenanthera colubrina	22.3	24.4	14.6	855.4	58.9
Persea americana	19.4	21.8	10.7	862.4	75.0
Ceiba aesculifolia	21.9	25.2	14.6	866.7	54.8
Beaucarnea recurvata	21.4	25.5	11.7	873.2	75.1
Quercus virginiana	18.8	26	8.2	877.7	126.1
Sapindus saponaria	21.3	25.9	12.1	890.0	86.1
Ceiba insignis	21	24.4	13.1	892.7	92.6
Caesalpinia pulcherrima	23.4	26	15.3	900.1	53.6
Lagerstroemia indica	16.8	24.8	7	917.7	101.5
Sabal palmetto	19.7	24.7	9.8	923.4	141.1
Cascabela thevetia	22.3	24.8	14.3	929.7	67.0
Cocculus laurifolius	19.6	24.6	9.3	939.4	83.6
Enterolobium contortisiliquum	21.4	24	14.2	946.3	71.0
Aloysia virgata	20.7	23	11.7	950.3	113.0
Cascabela thevetioides	22.1	24.8	16.1	953.1	78.0
Delonix regia	23.2	25.1	15.4	960.4	59.4
Peltophorum dubium	20.9	23.7	13.8	970.8	92.9
Ceiba speciosa	20.2	23.8	12.2	987.2	99.6
Psidium guajava	21.4	24.7	14.1	1002.6	76.3
Citrus japonica	18.1	24.4	7.9	1005.2	93.0
Vitex trifolia	23.5	25	14.7	1012.2	63.8
Handroanthus chrysotrichus	20.7	23.8	13.5	1017.6	90.0
Eugenia uniflora	20.3	23.8	12	1028.1	117.2
Osmanthus fragrans	16.7	24.7	6	1037.2	103.3
Carica papaya	22.2	25.3	13.8	1052.9	80.6
Rhaphiolepis indica	18	23.3	8.9	1076.3	117.0
Pereskia grandifolia	20.2	23.6	12	1107.3	80.6
Rhapis excelsa	19.9	24.8	10	1135.2	86.4
Coffea arabica	18.7	23.4	11.8	1136.2	92.8
Calliandra haematocephala	21.8	24.8	12.9	1138.9	110.3
Acer oblongum	15.9	23.6	6	1154.3	94.8
Podocarpus macrophyllus	17.5	23.8	7.3	1180.6	112.3
Xylosma longifolia	21.4	23.5	10.6	1195.8	56.4
Livistona chinensis	20.5	24.7	11.6	1279.9	162.6

Of the 474 species analyzed, **159** (33.5%) were ranked a score of 11, indicating they have been observed growing in the middle of their natural range in regions with a mean annual temperature equal to current MAT of Tucson. Of these 159 taxa, **80** taxa (50%) had a MAP of less than or equal to 500mm per year.

Species with Climate Rating 11 for Climate Scenario 2 (MAT 23.6°C) sorted by annual water needs.

Given the geographic location of Tucson Arizona, under climate scenario 2 (Emissions Limited Climate Scenario) the mean annual temperature is predicted to be 23.6 degrees Celsius (74.5 degrees Fahrenheit), maximum temperature of the hottest month as 41.6 degrees Celsius (106.88), and minimum temperature of the coldest month as 14.1 degrees Celsius (57.4 degrees Fahrenheit). The predicted annual precipitation is 288mm per year, and the predicted precipitation for the driest quarter is 17mm.

Taxon	MAT, °C	MHM , °C	MCQ, °C	MAP, mm/yea	MDQ, mm/qtr
Mariosousa willardiana	23.1	28.2	11.3	181.5	5.8
Vallesia laciniata	20.2	26.9	10.2	212.3	7.3
Forchhammeria watsonii	22.6	27.2	11.9	217.0	6.1
Boswellia sacra	22	23.3	11.9	227.3	40.3
Maytenus phyllanthoides	22.3	23.2	10.1	251.7	7.8
Bursera laxiflora	22.9	28.1	11.5	296.0	8.3
Acacia pruinocarpa	22.2	29.7	11.1	304.2	32.2
Coccoloba goldmanii	23.2	27.4	12.1	306.0	7.0
Fouquieria burragei	20.2	21.4	7.8	317.0	39.7
Parkinsonia praecox	21.7	27.9	11	317.9	13.0
Vachellia erioloba	19.5	21.5	8.2	320.0	33.0
Mimosa distachya	23.5	24.4	12.4	328.3	3.7
Piscidia mollis	22.9	28.8	11.8	355.4	12.1
Senegalia mellifera	20.6	22.1	8.7	373.3	38.0
Albizia sinaloensis	23.3	28.8	11.9	375.4	12.0
Vachellia tortilis	21.4	25.2	11.2	395.0	29.9
Stenocereus alamosensis	22.3	25.5	12.3	395.5	10.6
Brongniartia alamosana	22.6	28.4	11.6	401.5	15.3
Colophospermum mopane	21.3	24.7	12.1	401.8	28.0
Senegalia occidentalis	21.3	24.6	8	401.8	48.5
Vallesia glabra	23	28.5	14.3	408.1	14.0
Faidherbia albida	23.5	28.1	15.1	408.8	13.0
Populus mexicana	24.4	23.6	12.6	411.0	9.7
Eucalyptus victrix	21.7	27	11.9	434.6	34.4
Jatropha cordata	22.5	27.5	12.1	438.5	8.4
Coursetia glandulosa	22.7	27.8	12.1	441.5	14.0
Fouquieria purpusii	22.2	26.2	12.8	445.8	38.3
Fouquieria macdougalii	21.8	26.3	11.4	450.9	31.5
Havardia pallens	21.4	25.1	11	453.3	35.5
Opuntia wilcoxii	23.5	27.2	12.6	464.8	9.4
Fouquieria formosa	20.1	23.5	12.5	468.8	13.8
Sabal uresana	19.8	24.7	8.9	479.5	48.8
Cordia sonorae	23.6	27.8	12.5	480.0	12.8
Alluaudia procera	21.1	23.6	11.1	499.1	54.4

Taxon	MAT, °C	MHM , °C	MCQ, °C	MAP, mm/yea	MDQ, mm/qtr
Operculicarya decaryi	21.1	23.6	10.9	502.8	53.5
Bursera fagaroides	18.3	20.2	7.3	518.7	45.0
Callaeum macropterum	20.4	24.4	9.4	519.0	40.9
Pisonia capitata	24	27	14.1	528.8	10.0
Ipomoea arborescens	20.9	24.1	12.5	529.4	33.8
Brahea aculeata	22.2	26.6	12.3	540.1	26.5
Stetsonia coryne	20.1	23.3	10.3	540.4	48.0
Guaiacum coulteri	24.6	25.8	15.1	559.5	8.9
Ziziphus mucronata	21	25.5	13.2	571.0	27.3
Cordia myxa	22.2	25.5	11	573.1	50.9
Ravenea xerophila	22.1	24	12.9	579.3	47.8
Senegalia caffra	21.8	20.2	9.5	588.2	58.3
Kalanchoe beharensis	19.6	23.2	11.2	593.7	42.7
Prosopis juliflora	23.6	26.5	15.8	594.2	40.1
Bursera schlechtendalii	20.9	24	11.9	596.1	38.3
Vachellia kirkii	20.7	19.5	12.3	601.0	31.3
Jatropha malacophylla	23.5	25.2	14.7	604.1	8.3
Euphorbia trigona	19.6	20	7.4	606.0	47.7
Adansonia za	21.4	24	11.3	608.9	50.4
Vachellia aroma	18.8	23.3	9	619.1	75.8
Adenium obesum	23.3	26	13.6	622.5	37.7
Vachellia pennatula	19	20.1	7.9	632.2	63.2
Bursera grandifolia	23.8	25.8	15.8	645.8	12.0
Libidibia paraguariensis	20.9	24.1	11.1	646.6	73.4
Cereus hildmannianus	18.3	21.8	9.9	647.5	84.5
Phoenix pusilla	23	20.4	12.4	652.0	93.0
Vitex mollis	23.5	25.2	14.8	669.8	13.0
Dichrostachys cinerea	22.3	23.7	12.8	678.3	34.0
Senna atomaria	24.2	24.9	14.4	731.1	23.0
Acaciella angustissima	19.5	23.6	11.3	734.4	33.5
Sabal mexicana	22.3	26.5	13.2	747.8	70.7

Taxon	MAT, °C	MHM , °C	MCQ, °C	MAP, mm/yea	MDQ, mm/qtr
Cyrtocarpa edulis	21.4	23.7	13.4	755.4	68.4
Tecoma stans	20.6	24.6	13	793.0	50.1
Dalbergia sissoo	22.7	28.7	12.5	797.0	28.2
Hibiscus rosa-sinensis	20.4	22.8	9.8	812.1	56.4
Haematoxylum brasiletto	21.9	24.5	14.5	824.0	63.8
Cereus repandus	23	25.1	13.8	824.7	79.3
Chloroleucon tenuiflorum	22.4	24.6	12.9	828.0	85.0
Ehretia tinifolia	25.2	25.6	16.4	845.8	49.3
Sophora tomentosa	20.6	23.4	9.9	847.0	86.6
Anadenanthera colubrina	22.3	24.4	14.6	855.4	58.9
Persea americana	19.4	21.8	10.7	862.4	75.0
Ceiba aesculifolia	21.9	25.2	14.6	866.7	54.8
Bauhinia divaricata	24.8	24.9	16.1	871.0	58.4
Beaucarnea recurvata	21.4	25.5	11.7	873.2	75.1
Malpighia glabra	21.6	22.9	12.3	887.5	77.0
Sapindus saponaria	21.3	25.9	12.1	890.0	86.1
Ceiba insignis	21	24.4	13.1	892.7	92.6
Plumeria rubra	22.7	25.6	14.3	893.9	54.0
Caesalpinia pulcherrima	23.4	26	15.3	900.1	53.6
Leucaena leucocephala	22.8	25.4	14.6	900.6	63.8
Pithecellobium dulce	24.6	26.2	17.3	905.1	40.1
Lagerstroemia indica	16.8	24.8	7	917.7	101.5
Laguncularia racemosa	23.6	23.8	15.3	920.8	74.8
Cascabela thevetia	22.3	24.8	14.3	929.7	67.0
Avicennia germinans	23	25.1	14.5	944.8	76.0
Enterolobium contortisiliq	21.4	24	14.2	946.3	71.0
Albizia lebbeck	24.2	25.9	15.8	950.4	49.4
Solanum erianthum	24.1	26.2	15.5	950.4	51.0
Delonix regia	23.2	25.1	15.4	960.4	59.4
Annona squamosa	24.7	26.2	16.7	964.2	70.4
Peltophorum dubium	20.9	23.7	13.8	970.8	92.9
Ceiba speciosa	20.2	23.8	12.2	987.2	99.6
Enterolobium cyclocarpum	24.2	26.2	16.2	996.2	77.9
Rhizophora mangle	22.5	25	13.7	1002.4	99.6
Psidium guajava	21.4	24.7	14.1	1002.6	76.3
Citrus japonica	18.1	24.4	7.9	1005.2	93.0
Vitex trifolia	23.5	25	14.7	1012.2	63.8
Handroanthus chrysotrich	20.7	23.8	13.5	1017.6	90.0
Ficus trigonata	24.4	24.1	15.8	1024.4	51.0
Bismarckia nobilis	23.6	25.7	14.7	1025.7	62.3
Carica papaya	22.2	25.3	13.8	1052.9	80.6
Mangifera indica	24.3	25.8	16.1	1065.0	57.6
Crescentia alata	24.1	26.2	15.7	1070.7	46.0
Ficus insipida	23.5	23.7	16	1093.3	87.5
Annona muricata	22.8	24.6	15.6	1112.6	95.8
Cassia fistula	24.7	26	16	1114.5	57.0
Ficus pertusa	23.4	23.6	14.6	1131.3	80.4
Rhapis excelsa	19.9	24.8	10	1135.2	86.4
Coffea arabica	18.7	23.4	11.8	1136.2	92.8
Calliandra haematocephal	21.8	24.8	12.9	1138.9	110.3
Hamelia patens	22.3	25.3	13.2	1162.4	94.8
Caryota mitis	23	25	13.8	1202.2	87.8
Livistona chinensis	20.5	24.7	11.6	1279.9	162.6
Manihot esculenta	22.6	24.9	15.2	1338.3	95.5
Pachira aquatica	22.8	24.9	14.4	1354.7	105.3
Schizolobium parahyba	21.8	23.7	14.2	1355.7	115.5
Coffea canephora	21.5	24.3	14.3	1391.0	88.0
Theobroma cacao	22.8	25	15.2	1476.2	129.7

Of the 474 species analyzed, **123** (25.9%) were ranked a score of 11, indicating they have been observed growing in the middle of their natural range in regions experiencing the mean annual temperature predicted for Tucson in 2050. Of these 123 taxa, **34** taxa (27.6%) had a MAP need of less than or equal to 500mm per year.

Species with Climate Rating 11 for Climate Scenario 3 (MAT 26.5°C) sorted by annual water needs.

Given the geographic location of Tucson Arizona, under climate scenario 3 (Business as Usual Climate Scenario) the mean annual temperature is predicted to be 26.5 degrees Celsius (79.7 degrees Fahrenheit), maximum temperature of the hottest month as 44.4 degrees Celsius (111.9), and minimum temperature of the coldest month as 16.4 degrees Celsius (61.52 degrees Fahrenheit). The predicted annual precipitation is 264mm per year, and the predicted precipitation for the driest quarter is 14mm.

Taxon	MAT, °C	MHM , °C	MCQ, °C	MAP, mm/year	MDQ, mm/qtr
Boswellia sacra	22	23.3	11.9	227.3	40.3
Prosopis cineraria	22.6	23.5	8.6	284.2	42.0
Vachellia tortilis	21.4	25.2	11.2	395.0	29.9
Faidherbia albida	23.5	28.1	15.1	408.8	13.0
Vachellia nilotica	23.8	26.5	12.8	470.4	30.3
Calotropis procera	24.8	25.4	14.7	473.9	14.5
Senegalia senegal	23.4	23.5	9.1	477.7	76.7
Eucalyptus microtheca	24.1	29.5	13.9	491.8	17.6
Parkinsonia aculeata	22	27.9	12.4	496.6	24.4

Taxon	MAT, °C	MHM , °C	MCQ, °C	MAP, mm/year	MDQ, mm/qtr
Guaiacum coulteri	24.6	25.8	15.1	559.5	8.9
Ziziphus mucronata	21	25.5	13.2	571.0	27.3
Vachellia sieberiana	23.7	21.6	11.8	585.8	34.5
Senegalia caffra	21.8	20.2	9.5	588.2	58.3
Prosopis juliflora	23.6	26.5	15.8	594.2	40.1
Jatropha malacophylla	23.5	25.2	14.7	604.1	8.3
Vachellia valida	23.8	21.8	11.5	621.3	51.7
Adenium obesum	23.3	26	13.6	622.5	37.7
Phoenix pusilla	23	20.4	12.4	652.0	93.0
Fouquieria leonilae	25.1	28.3	15.7	677.3	10.4
Dichrostachys cinerea	22.3	23.7	12.8	678.3	34.0
Chloroleucon mangense	25.7	25.2	16.6	724.4	20.8

Taxon	MAT, °C	MHM , °C	MCQ, °C	MAP, mm/year	MDQ, mm/qtr
Moringa oleifera	24.2	24.3	15	801.0	45.9
Cereus repandus	23	25.1	13.8	824.7	79.3
Corymbia papuana	24.1	24.6	14.8	837.9	17.1
Melaleuca leucadendra	24	26	15	913.8	45.8
Azadirachta indica	26.3	27.6	18.2	940.7	36.1
Avicennia germinans	23	25.1	14.5	944.8	76.0
Phoenix sylvestris	23.7	26.9	13.7	946.5	58.5
Albizia lebbeck	24.2	25.9	15.8	950.4	49.4
Annona squamosa	24.7	26.2	16.7	964.2	70.4
Enterolobium cyclocarpu	24.2	26.2	16.2	996.2	77.9
Bismarckia nobilis	23.6	25.7	14.7	1025.7	62.3
Crescentia cujete	24.2	25.9	16.7	1063.4	79.4
Mangifera indica	24.3	25.8	16.1	1065.0	57.6
Cassia fistula	24.7	26	16	1114.5	57.0
Caryota mitis	23	25	13.8	1202.2	87.8

Of the 474 species analyzed, **36** (7.6%) were ranked a score of 11, indicating they are observed experiencing the predictive 2090 climate of Tucson in the middle of their natural range. Of these 36 taxa, **9** taxa (25.0%) had a MAP need of less than or equal to 500mm per year.

**All results data are available as a MS Office Excel file at this web address: https://arboretum.arizona.edu/research/evaluating-climate-risk-tucson-tree*

Discussion:

How might these results be useful?

The risk ratings for the tree species evaluated under 3 climate analyses provide insights to guide thoughtful accession planning for the decades to come and and underscore the need to protect diversity as many trees currently grown in Tucson appear to be at risk based on current or predicted MAT in the region unless excessive supplemental water is provided. As such, the project illustrated opportunities to improve the tree selection criteria of the Tucson collections while respecting the need to conserve water.

Of the 474 species analyzed in the Current Climate Scenario, 80 specimens are observed occurring in the middle of their natural range at a MAT of 21°C, while falling within the Collection Policy's water requirements of less than or equal to 500mm per year. Indicating that 16.9% of the 474 taxa evaluated are potentially adapted to the current Sonoran Desert Climate of Tucson without supplemental irrigation or strategic placement within a cooler microclimate. As the guidelines set forth in the Campus Arboretum's Collections Policy sets 500mm as an upper limit, these 80 taxa fall within the criteria and will be further evaluated to determine their suitability for planting for current climate. Additionally, of these 80 species, 14 taxa also rate 11 in the limited emissions climate scenario (MAT 23.6°C). As such, these 14 taxa are not only potentially adapted for the current climate but, may have the potential to be adapted to the predicted climate of 2050. **For this reason, we tentatively point to the greatest promise for these 14 taxa to perform well under current and/or predictive future climate in Tucson, AZ. These 14 will be the first explored in our subsequent evaluation by industry practitioners and for assessing whether their maximum and minimum temperature thresholds correspond to those typical of Tucson (now and in the future).**

For the Emissions Limited Scenario, 35 specimens have been observed growing in the middle of their natural range in regions with a MAT of 23.6°C, while also falling within the Collection Policy's water requirements of less than or equal to 500mm per year. These species represent 7.34% of the 474 taxa evaluated are potentially adapted to the near-future climate of the Sonoran Desert Climate of Tucson without intervention of supplemental irrigation or strategic placement within a cooler microclimate. As these 35 taxa fall within the guidelines set forth in the Campus Arboretum's Collections Policy, they will also be further evaluated to determine their suitability in near-future accession planning. Of these 35 species, 3 also appear in the Business as Usual climate scenario. These 3 taxa are tentatively promising to perform well under both the predicted climate of Tucson, AZ for both 2050 and 2090.

For the BUA Scenario, 9 taxa are observed occurring in the middle of their natural range at a MAT of 26.5°C, while falling within the Collection Policy's water requirements of less than or equal to 500mm per year. Indicating that 1.9% of the 474 taxa evaluated are potentially adapted to the predictive distant-future climate of 2090. Upon comparing the results from all three climate scenarios, this project also identified 1 species of tree of particular recognition, *Vachellia tortilis*, as it has been observed occurring in the middle of its natural range at the MAT of each climate scenario and requires less than 500mm of annual precipitation.

In summary, there is 1 taxa that has been observed occurring in the middle of its natural range at the MAT of each of the 3 climate scenarios and requires less than 500mm of annual precipitation, 13 taxa having been observed occurring in the middle of its natural range at the MAT of both the Current and Emissions Limited scenarios only and requiring less than 500mm of annual precipitation, and 2 taxa having been observed occurring in the middle of its natural range at the MAT of both the Emissions Limited and Business as Usual scenarios only and requiring less than 500mm of annual precipitation. Together, this generates a list of 16 taxa as priority for further evaluation.

We consider the use of MAT as a valid parameter for initial evaluation of species performance potential. As such, those species observed in regions with the same MAT as Tucson currently, or in the two predicted climate change scenarios considered, may include a subset of species with better temperature performance than other species evaluated. For this reason, we tentatively point to the promise of these 16 taxa to perform well under current and/or future climate in Tucson, AZ. However, while the mean temperature may correlate with plant performance generally, it is the temperature extremes that better predict survival. As the high and low temperatures used to derive the mean are not known, we would like to further refine the list based on the breadth of temperatures experienced in the regions where these trees have been observed. This data may be obtained from the Global Tree Database, other online records and from global practitioners reporting performance based on their use/experience cultivating those species. Given the temperature range experienced in Tucson historically is approximately 15°F to 115° F, we would like to refine the list of species we've collected by comparing the full span of temperatures in their range with that observed in Tucson to better evaluate potential performance. For species with a similar span, we might recommend prioritizing planting in the Tucson area. For species adapted to regions where temperatures fall below 15°F, we might recommend planting those in a cooler or protected Tucson microclimates. For species adapted to temperatures hotter than 115 ° F, we might recommend those be planted in warmer microclimates or areas where supplemental water can be provided. Further, recognizing the 474 taxa evaluated are limited to those previously grown in Tucson (and also limited by those appearing in the Global Tree Database), we will complement our work by evaluating additional species in the Campus Arboretum's "Wishlist", which are tree species not commonly cultivated in Tucson. Climate Assessment will be repeated using the same criteria (MAT and precipitation <500mm) and the resulting species list will be refined as described above. As a guide to planting and curation, The University of Arizona Campus Arboretum Collections Policy will be updated to include the recommended species which fall within the temperature range and below the precipitation threshold defined in the standard. We also hope the work will yield a broader range of tree species to recommend for planting or production in the nursery trade given their superior potential to perform well in Tucson.

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