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CLIMATE CHANGE

Preparing Indiana's Urban Forest for Climate Change

Introduction

Among the steel and concrete that make up the urban environment, trees provide welcome relief from heat and potentially unfavorable sights and smells. Trees provide value from ecosystem services, which can refer to any of the benefits humans obtain from nature. Trees in the built environment provide many benefits, such as storing carbon, reducing air temperature and air conditioning costs, filtering air and water pollutants, intercepting rainwater to reduce flooding, and increasing aesthetic value **(Figure 1)**. Trees can also produce undesirable services, called ecosystem disservices. These include releasing allergens, such as pollen and other volatile organic compounds (VOCs), which can cause respiratory problems and contribute to ozone production. However, ecosystem services of urban trees far outweigh the disservices, and people usually want more trees in their cities (Mullaney et al., 2015).

Many ecosystem services that trees provide increase the resilience of cities. Resilience is the ability of a system to respond to and

Figure 1. *Some of the various ecosystem services and disservices trees provide.*

recover from disturbances, such as floods or fires. Trees can increase the resilience of cities through ecosystem service provision, but they also must have resilience themselves to survive in stressful urban environments. Some tree species have greater capacities to survive under variable environmental conditions. For example, the leaf types or root structures may give certain trees greater drought tolerance, affording them greater resilience in the extreme environment of a city. In urban forests with many trees, the diversity of tree species can increase the resilience of a forest compared to an ecosystem with only a few species, because different species respond better to different disturbances. If a pest invades an urban forest primarily made up of one tree species that is vulnerable to the pest, that forest will be much more affected than one with many species, which could buffer the impacted trees and ensure the entire forest does not get disrupted. Currently, Indiana urban forests are dominated by hardwood genera, such as oaks and maples. Due to climate change, however, the habitats in Indiana may become suited to different genera.

Climate change is already disrupting the climate of Indiana. The growing season is becoming warmer, drier, and longer (Reynolds et al., 2018). The frequency and intensity of storms, as well as the prevalence of new pests and pathogens, are also likely to continue to increase. These factors may affect tree health and result in changes in habitat range for some tree species. Some species may migrate north out of Indiana, others will still be able to survive here, and new species that do not currently live in Indiana may become more common **(Figure 2)**. Species selection for urban trees will have to be adjusted to maintain sustainable tree health and ecosystem service provision.

This report summarizes ecosystem services provided by common urban tree species in Indiana, as well as habitat range shifts due to climate change. Together, this information can be used now to guide urban tree selection to ensure trees will continue to provide ecosystem services and help cities adapt to changes in environmental conditions into the future.

Methods

First, we generated a list of tree species planted in cities throughout Indiana. From this list, we selected the most common urban trees and adjusted the list further to remove trees considered "undesirable" in urban settings (City of West Lafayette, 2021). Next, we compiled common traits of tree species and information about their projected ranges under different climate change scenarios (Reynolds et al., 2018) into **Table 1.** We included ecosystem service and disservice values for each species of urban tree from the i-Tree Species Selector tool (i-Tree, n.d.). The resilience scores are based on Relative Urban Stress Tolerance (RUST), which includes a combination of environmental tolerances, such as salt, sun, and pH (Scharenbroch, 2011). More information on how we collected the information in this report can be accessed in the Appendix, Page 8.

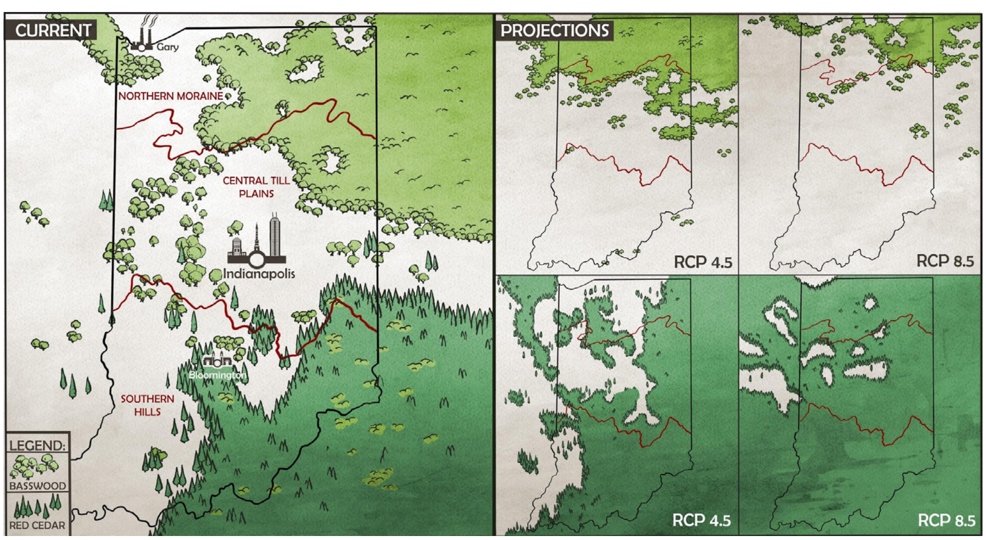

Figure 2. *The three climate zones of Indiana overlaid with examples of how favorable tree habitats are projected to change by year 2100 under two climate pathways. The favorable habitat of American basswood retreats north under RCP 4.5 and 8.5 scenarios. The favorable habitat of eastern red cedar pushes north under RCP 4.5 and 8.5 scenarios.*

Results

Habitat suitability, or favorability, for common urban tree species in Indiana is expected to change, which will affect their abilities to thrive in urban areas. Species vary in their ability to respond to changing environmental conditions as well as their ability to provide ecosystem services (Table 1).

For some species, changes in the favorability of habitat are the same across the three geographic zones in Indiana. Conditions are expected to become more favorable in Northern Moraine, Central Till Plains, and Southern Hills habitats for eastern hophornbeam (*Ostrya virginiana*). For other species, however, changes in habitat favorability are expected to vary by region. For the Ohio buckeye (*Aesculus glabra*), habitat favorability is expected to stay the same in the Northern Moraine, increase in the Central Till Plains, and decrease in the Southern Hills. For most species, habitat favorability changes are similar under the two climate change projections (RCP 4.5 and RCP 8.5), so if a species is expected to decrease under RCP 4.5, then it is also expected to decrease under RCP 8.5. However, for northern red oak (*Quercus rubra*) and white oak (*Quercus alba*), the habitat favorability change predictions shift from increase to decrease, depending on the emission scenario.

In the Northern Moraine region under the RCP 4.5 climate projection scenario, habitat favorability is expected to decrease for three species and remain the same for nine species (Table 1). Reductions in habitat favorability will likely result in declines in growth and survival, which will reduce the ecosystem services provided by the affected species. For example, drier conditions during the growing season may limit growth, which will in turn reduce carbon storage capacity, leave fewer resources for trees to grow

Table 1. *Ecosystem services, disservices, and resilience for a subset of common Indiana trees*

Growth rate of tree species can be slow (S), moderate (M), or fast (F). Lifespans were grouped as short, medium (Med.), and long. If a species abundance is expected to increase, it is shown with an up arrow (↑), and if a species abundance is expected to decrease, it is displayed with a down arrow (↓). Species where no change in abundance is expected are displayed with a dash (–), and species that are expected to move into a region but are not currently found there are represented with the word "New." For services, disservices, and resilience factors, more plus signs (+) indicate better performance.

	Species Information				Habitat Change Under RCP						Ecosystem Services & Disservices							Resilience	
	Size	Species	Growth Rate	Lifespan	Northern Moraine 4.5	Northern Moraine 8.5	Central Till Plains 4.5	Central Till Plains 8.5	Southern Hills 4.5	Southern Hills 8.5	Carbon Storage	Air Temp. Reduction	Pollutant Removal	Water Interception	Aesthetics	Low Allergenicity	Low VOCs	Drought Tolerance	Stress Tolerance
Broadleaf Deciduous	Small or Small/Medium	Eastern hophornbeam	S-M	Med.	↑	↑	↑	↑	↑	↑	++	+++	+++	+++	++	++	++	+++	+++
		Ohio buckeye	S-M	Med	–	–	↑	–	↓	↓	+++	+++	+++	+++	+++	++	++	++	++
		Serviceberry	M	Med.	↓	↓	–	–	↓	↓	++	+	+	+	+++	+++	+++	+++	++
	Medium or Medium/Large	Hackberry	F	Med.	↑	↑	↑	↑	↑	↑	+++	+++	+++	+++	++	+	++	+++	++
		Red maple	M	Med.	–	–	–	–	↓	–	+++	+++	+++	+++	+++	++	+	+	++
		River birch	M	Short	–	–	↑	↑	–	–	++	+++	+++	+++	++	++	++	+	++
		Swamp white oak	M	Med.	–	–	–	–	↓	↓	+++	++	+	++	++	+	+	+++	+++
		Honeylocust	F	Med.	↑	↑	↑	↑	↑	↑	+++	+	+	+	++	++	+	+++	+++
	Large	Bur oak	S	Long	–	–	–	–	↓	↓	+++	++	+	++	+	+	+	+++	++
		Northern red oak	M-F	Long	↑	↓	↑	↓	–	↓	+++	++	+	++	++	+	+	+++	++
		Sycamore	M-F	Long	–	–	↑	↑	↑	↑	+++	+++	+	+++	++	+	+	+	++
		White oak	S	Long	↑	↓	↑	–	–	–	+++	++	+	++	++	+	+	+++	++
		Pecan	S	Long	New	New	New	New	↑	↑	+++	+++	+++	+++	+	+	+	+	++
		Bitternut hickory	S	Med.	↑	↑	↑	↑	↑	↑	+++	+++	+++	+++	++	+	++	+	++
		Sugar maple	S	Med.	–	–	↓	↓	↓	↓	+++	+++	+++	+++	++	++	++	+	+
		American beech	S	Long	–	↓	↓	↓	↓	↓	+++	+++	+++	+++	++	++	++	+	++
		Sugarberry	F	Med.	New	New	New	New	↑	↑	+++	+++	+++	+++	+	+	++	++	+++
		Sweetgum	M-F	Long	New	New	↑	↑	↑	↑	++	+++	+	+++	++	++	++	+++	+++
		American basswood	M-F	Med.	↓	↓	↓	↓	↓	↓	+++	+++	+++	+++	++	++	++	++	++
		Yellow-poplar	M-F	Med.	↑	↑	↓	↓	↓	↓	+++	+++	+++	+++	+++	+++	++	+	++
		American elm	M-F	Med.	↑	↑	↑	↑	↑	↑	+++	+++	+++	+++	++	+	+++	+++	+++
Evergreen Conifer	Small or Small/Medium	Eastern redcedar	S	Long	↑	↑	↑	↑	↑	↑	++	++	++	++	++	+	++	+++	++
		Virginia pine	S-M	Short	–	–	–	–	–	–	++	++	++	++	+	+++	+	+++	++
	Medium or Medium/Large	Loblolly pine	F	Med.	NA	New	New	New	New	New	++	+++	+++	+++	+	+++	+	++	++
	Large	Eastern white pine	M-F	Long	↓	↓	↓	↓	↓	↓	+++	+++	+++	+++	+	+++	+	+	+

leaves, and reduce their cooling effect and stormwater interception abilities. At the same time, environmental conditions are predicted to become more favorable for eight species, and changes in conditions may allow three new species to move into the Northern Moraine region. A longer growing season may increase growth and survival for these species, allowing them to increase carbon sequestration and grow more leaves to catch more pollutants, provide more shade, and intercept more rainfall. Greater amounts of carbon dioxide in the atmosphere due to human activities have been found to increase tree growth.

The Central Till Plains and Southern Hills regions exhibit the same patterns, with generally more increases in habitat favorability than decreases. It is feasible to pivot tree planting to the species more likely to thrive in these habitats in the future while maintaining biodiversity in species to help ensure ecosystem services will continue to be provided by the urban forest in these regions.

Indiana is in the Central Hardwood Region, which is dominated by deciduous tree species with a few coniferous species. With climate change, habitat ranges of most tree species are expected to move northward, which will likely push out most coniferous species. For example, habitat changes in Indiana will result in less favorable conditions for the eastern white pine (*Pinus strobus*) across all regions in the state. The ecosystem services provided by this species will likely decline and may struggle to persist. However, habitat favorability in Indiana will increase for two conifer species: eastern redcedar (*Juniperus virginiana*) is expected to increase its range, and loblolly pine (*Pinus taeda*) is expected to move into Indiana as new habitat. Adjustments to the selection of coniferous species planted now could maintain the ecosystem services provided in the future.

Figure 3. *Street trees shading and adding color to a residential street.* Photo Credit: Lindsey Purcell

There is high variability in resilience among tree types and tree sizes. The majority of species on this list have a moderate resilience value ("++"). Species with low resilience values ("+") generally decrease in habitat in Indiana under both climate change scenarios (RCP 4.5 and RCP 8.5), and species with high resilience values ("+++") increase in habitat. Species with medium resilience values ("++") may either decrease or increase under climate change projections, or they have mixed changes in species increase/decrease depending on the region of Indiana or the climate projection scenario.

Discussion

The effects of climate change continue to intensify in Indiana, which makes it increasingly important to consider how environmental change affects tree survival in planting decisions, especially with a prolonged establishment period. When selecting trees, we must consider which ecosystem services are most desired and which ecosystem disservices are least desired. It is also important to understand the preferred habitat of the tree species to maximize benefits and minimize inputs. Species profiles must be considered before selection and planting to avoid issues with messy fruit and to increase chances of tree survival. There are other credible sources available which can be applied to confirm compatibility based on these considerations (The Morton Arboretum, 2015; *Plant Finder*, n.d; Purcell & Daniel, 2016). Table 1 can be used as a guidebook to select species equipped to adapt to changing environmental conditions. Selecting drought-tolerant, resilient species whose ranges are expected to be maintained or increased in Indiana will ensure that the urban forest can continue to provide ecosystem services in the future. Urban foresters can use this table to select species that meet the needs of urban areas, be able to adapt to climate changes and will increase their resilience within harsh urban areas.

Table 1 provides information on common services and disservices widely considered most important, but service importance will vary depending on the location of the tree and planting goals. Pollutant removal may be more important along busy roads because the trees can buffer nearby human spaces from the pollutants from cars **(Figure 3).** Stormwater interception is an especially important service, in urban areas covered with impervious pavements, to reduce runoff during storm events, potentially decreasing flooding. Air temperature reduction from trees is important in cities, which are generally hotter than surrounding areas (Oke,

Figure 4. *Large canopy trees shade buildings.* Photo Credit: Lindsey Purcell

1982). Furthermore, trees planted near buildings can help reduce energy needs for cooling homes during the summer and heating during the winter. This lowers both costs and emissions associated with electricity production (**Figure 4**; Ko, 2018). Tree selection suited to the changing climate will maintain these benefits into the future.

Cities may also serve as stepping stones for tree species (Han et al., 2021). Because of higher temperatures, the climates of cities often resemble the climates of regions farther south, which may allow cities to support more southern species. City foresters can look to the south for potential species to plant that will survive as temperatures increase. A caveat: Though the climate of Indiana will be warmer, winters matching historical temperatures can still occur and may be less predictable in severity and frequency. New southern tree species may not survive harsh winter temperatures, even if the cold spells persist for only short time periods. The selection of resilient species able to survive in highly variable climates is likely the best strategy to maintain trees in the urban forest as climate change continues.

Resilience scores (RUST) are a combination of many tolerance factors, and some tolerances will be important only if trees are planted in certain locations (Scharenbroch, 2011). For example, in states with cold winters like Indiana, street trees must possess some level of salt tolerance, since salt is used for reducing ice on roads in winter **(Figure 5).** However, the importance of different resilience factors may also change as the climate changes. Most coniferous species are vulnerable to salt and are generally unable to survive as street trees or in active parking lots. However, as the climate warms, snow in Indiana may become less frequent, which may result in reductions in salt use, allowing conifers to grow nearer to roads. While salt tolerance may become

Figure 5. *Street trees and bioswales buffer shops and a bike lane from the street.* Photo Credit: Lindsey Purcell

less important in the future, drought tolerance is likely to become more important. City foresters can use drought tolerance, shown in Table 1, to determine if a tree species will be resilient to increased temperatures in Indiana. Supplemental irrigation could prevent trees from dying; however, it is not ideal to need to artificially support a tree when another species selection could possibly provide similar ecosystem services with fewer maintenance inputs.

Tree species differ in their characteristics and ability to provide certain ecosystem services, but all established trees provide some environmental benefits. Additionally, genera and species diversity in the urban forest is very important for increasing the resilience of cities to climate change. In application, when multiple trees will be selected for an area, it is considered best practice to choose different genera and species which provide a variety of services and are resilient to a range of conditions and disturbances. This reduces the likelihood that all of the trees will die after a disturbance, such as a flood or drought, and they are less likely to all be affected by devastating pests.

Tree selections that include an expanded palate of deciduous and coniferous trees can diversify ecosystem services provided **(Figure 6).** Conifers retain their needles throughout the year, so they provide benefits such as water retention, aesthetics, and insulation even during the winter, when deciduous tree species have reached dormancy, shedding their leaves. However, deciduous trees have larger canopies in the summer, allowing for greater shade provision and reductions in air temperature **(Figure 7).**

Figure 6. *A mix of coniferous and deciduous trees provide a range of ecosystem services.* Photo Credit: Kanaan Hardaway

The purpose of this report is to serve as a tool to guide urban foresters, arborists, and planners with sustainable tree selections for the built environment. The goal is to better inform tree selections capable of surviving in Indiana in the future and specialize in the provision of various ecosystem services. A more diverse urban forest will allow cities to adapt to changes in environmental conditions while mitigating some of the concerns associated with climate change.

Figure 7. *Park-goers lounge in the shade of a tree.* Photo Credit: Lindsey Purcell

Conclusion

We are already experiencing the effects of climate change on local weather patterns and seasonal variations in Indiana. By acknowledging how changes in habitat in the coming decades will favor certain genera and species over others, we can adjust the trees we select to help ensure the urban forest continues to provide important functional benefits. The benefits trees provide can help mitigate some of the problems associated with climate change. For example, carbon sequestration can offset some of the carbon emissions contributing to climate change. The cooling effect urban trees provide can reduce ambient air temperatures in urban areas and heat islands found in cities. To counteract increased storm events, stormwater interception from tree canopy can reduce rain runoff, which creates combined sewer overflow issues in cities and other flooding problems. We must begin preparing the urban forest now if we are to maintain these important ecosystem services in the future. Research indicates that climate change is inevitable, and it is critical to adapt urban forests now for our future and quality of life.

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APPENDIX

Species Selection

We started by generating a list of tree species commonly planted in cities throughout Indiana. Tree species were selected by combining species lists from a variety of sources (i-Tree, n.d.; Reynolds et al., 2018). From this combined list, tree species were eliminated if they were considered "undesirable" in urban areas (City of West Lafayette, 2021). Common persimmon *(Diospyros virginiana)*, silver maple *(Acer saccharinum)*, green ash *(Fraxinus pennsylvanica),* and white ash *(Fraxinus americana)* were all included on the main list but were removed from the final list of this publication because they were considered undesirable due to messy fruit, weak wood, and borer insects, respectively (City of West Lafayette, 2021). Some species were considered undesirable because of the current high populations (e.g., red maple *(Acer rubrum)* and sugar maple *(Acer saccharum)*), but were included because their density is heterogeneous across cities.

Conversely, some species were included or excluded in favor of a representative diversity of tree species. For example, black oak (*Quercus velutina*) was on the main list and not considered undesirable, but this tree was excluded from the final list because there were four other more common *Quercus* species already included (City of West Lafayette, 2021). Meanwhile, *Carya* species are common in Indiana and were not listed as undesirable, so bitternut hickory *(Carya cordiformis)* and pecan *(Carya illinoinensis)* were included in the final list. Sugarberry *(Celtis laevigata)*, American basswood *(Tilia americana)*, and American elm *(Ulmus americana)* were all included to provide more genus diversity, especially since they all generally have high ecosystem service values and were not considered undesirable. Virginia pine *(Pinus virginiana)* and loblolly pine *(Pinus taeda)* were not on the main list, but they were also not undesirable, so they were included on the final list to increase the number of conifer species. American hornbeam *(Carpinus caroliniana)* and eastern redbud *(Cercis canadensis)* were removed because data for ecosystem service and disservice values could not be found for these species using the i-Tree Species tool.

Tree Species Information

Tree species type (broadleaf deciduous versus evergreen conifer), size, growth rate, and lifespan were included for each species to provide helpful background information. Tree species type was determined from the i-Tree species list (n.d.). This list was also used for tree size, but it was checked with The Morton Arboretum (TMA) Tree Species List (The Morton Arboretum, 2015). If the two lists had differences, the values were either given as a range or averaged. For example, if one list categorized a tree as "small" and the other list said it was a "medium" size, the tree was listed as "small/medium." If one list categorized a tree as "large" and another as "small," the tree was listed as "medium." Similarly, growth rate values were taken from two sources (The Morton Arboretum, 2015; Nowak et al., 2002). If these lists had different values, the range was given. For example, if one list categorized a tree's growth rate as "slow" and the other categorized it as "moderate," it would be categorized as "slow-moderate." Lifespan information was also compiled from multiple sources (Nowak et al., 2002; Scharenbroch, 2011). If lifespan was found in the "Urban Trees for Carbon Sequestration" document with only numerical year values, they were grouped into short, medium, and long lived based on how trees with similar numerical lifespans were grouped in the document from Nowak et al. (2002).

Habitat change information was included in the table to provide information about which species would be most likely to survive in different regions of Indiana in the future (Reynolds et al., 2018). As shown in Table 1, arrows pointing toward the top of the page were used to show species that will increase, arrows pointing toward the bottom of the page were used to show species that will decrease, and dashes were used to show species that are not expected to change.

Ecosystem Service and Disservice Values and Resilience

Most of the values for ecosystem services and disservices were gathered from the i-Tree Species tool. For the majority of species, the location was set to Lafayette in Tippecanoe County, Indiana, USA. However, because Indiana is a new habitat for some of these tree species, an alternate location in their current ranges was used. For pecan *(Carya illinoinensis)* and sweetgum *(Liquidambar styraciflua)*, Jefferson County, Kentucky, USA, was used, and Polk County, Tennessee, USA, was used for loblolly pine *(Pinus taeda)*. A sample of species that were located in both Tippecanoe County and Jefferson County were confirmed to have the same ecosystem service values in both locations. For all ecosystem services and disservices, no minimum or maximum height requirements were entered, and the service of interest was set to an importance of ten, with the importance levels of all other functions set at zero. Carbon storage, air temperature reduction, pollutant removal using the overall rate, and streamflow reduction were used for the service values. Allergenicity and VOC emissions were used to evaluate disservices. The report type was selected to display all tree species for the location, and individual species' relative performance values based on percentages. If the ecosystem service performance of a species had a value in the top 10%, 20%, or 30% of all species, they were recorded with a value of "+++" in Table 1. Species in the top 40-70% were given a value of "++," and species in the top 80%, 90%, and 100% were displayed with a "+."

Values for the aesthetic ecosystem services were not available from i-Tree. To assign relative aesthetic value, species were given a point for presence of showy flowers, ornamental fruit, and fall foliage color for a maximum of three points and a minimum of zero points based on information from the TMA Tree Species list and the USDA Plant Database (The Morton Arboretum, 2015; USDA, NRCS, 2022). Then, species with a value of zero were given a "+," species with one point were marked as "++," and species with two points were given a "+++." No species on the final list had three points for aesthetics.

The resilience metric was determined from Relative Urban Stress Tolerance (RUST) (Scharenbroch, 2011). The RUST factor is a combination of hardiness based on temperature tolerance, pH range tolerance, sun tolerance, insect or disease tolerance, physiological or environmental tolerance, moisture tolerance, salt tolerance, soil texture tolerance, and compaction tolerance (Scharenbroch, 2011). Each factor was ranked from -1 to 1, and the resulting sum is the RUST factor. These values were normalized to a scale of one to three and then translated into the table with the number of "+"s that their number indicated. Drought tolerances were mostly obtained from the TMA Tree Species list. Drought tolerance for Virginia pine *(Pinus virginiana)* and loblolly pine *(Pinus taeda)* could not be found in that list, as the values were identified for the other tree species but were compiled from other sources (Gilman & Watson, 1994; Matallana-Ramirez et al., 2021; *Loblolly Pine*, 2022). Species that were "intolerant" to drought were displayed with a "+," species with a "moderate" drought tolerance were given "++," and species considered "tolerant" to drought were shown in the table with "+++."