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PLANNING URBAN FORESTS IN A CHANGING CLIMATE

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PLANNING URBAN FORESTS IN A CHANGING CLIMATE

by

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Abstract:

As the effects of negative effects of climate change are realized, urban forests a means to reduce the potential damage and adverse conditions in urban areas (Wolf, et al., 2020) (Livesley, McPherson, & Calfapietra, 2016) (Xiao & McPherson, 2002). Preserving these resources is becoming more difficult however, as the trees that make up urban landscapes become less adapted to current conditions with every passing year (Aitken, Yeaman, Holliday, Wang, & Sierra, 2008). Changes in climate and world systems also point to invasive pests becoming greater threats to urban forest resources with time (Tubby & Webber, 2010) (Amberger et al., 2017). In order to preserve the benefits these ecosystems provide, and buffer against harsher conditions as a result of climate change, urban forest trees will need to be planted using trees adapted to conditions individual cities are projected to experience (Aitken, Yeaman, Holliday, Wang, & Sierra, 2008). Additionally, more diverse urban forests need to exhibit higher diversity at the genus level, such that damage from pests doesn't interrupt ecosystem functions (Driesche & Hoddle, 2016). Further climate research is needed to determine optimal future conditions to plan ahead for, and local research will be needed during implementation to allow for healthy forests in specific climate conditions.

Importance of urban forestry and threats to its future

Urban forests are a defining characteristic of many urban environments, providing contrast from the built environment, and allowing nature to permeate areas of the densest cities. Urban forestry is a practice defined as the planting, maintenance, care and protection of tree populations of urban settings. Urban forestry focuses not only on concentrations of tree containing areas like parks, but along boulevards, rivers, greenways, and anywhere else trees are found in urban settings. Urban forestry isn't just focused on individual trees however, the greater practice seeks to use engineering and city planning to create urban ecosystems that service the communities they're a part of (American Forests, 2019).

Urban forests provide much more than aesthetic value however. With climate change putting stress on our environments urban or otherwise, and the continuing global shift towards urbanization, the increasing need to understand urban forests has given us evidence of benefits they provide, how best to create and manage them, and many of the issues urban forests are facing today (Salmond, et al., 2016). Urban forests do not provide benefits in a vacuum however, as cities face many different issues than rural areas, and the interactions between urban forests' ecosystem services and differing demands of cities sculpt urban forestry into a science that requires an equally systemic approach (Haase, et al., 2014).

Four categories of ecosystem services have been put forth as a means of both understanding benefits to communities, organizing how those ecosystems should be managed depending on desired outcomes, and to help protect against maximizing single variable output. Initially this framework was devised as the millennium ecosystem assessment, but has been recently adapted to function in urban forestry planning. The revised categories are as follows: Provisioning services, regulating services and related health benefits, supporting habitat services, and cultural services (Gómez-Baggethun, et al., 2013).

Provisioning, or the production of food and/or water resources, is often neglected in urban forests, both in practical application and research. There are very few studies examining urban forests engineered to provide food to residents, with reviews of urban forestry literature even remarking on a lack of emphasis on food production across the board (Russo, Escobedo, Cirella, & Zerbe, 2017). Provisioning water is a more complicated matter however. Urban forests benefits pertaining to water fall into more than one category, with most of their benefits falling into regulating services. Trees provision water in a sense through storage, altering the surrounding microclimates, and mitigating potential water losses as a result of climate change (Lee, et al., 2017).

Regulatory services, or trees ability to regulate environments and ecosystem services, are more frequently explicitly planned for in urban settings, and are generally more understood (Gómez-Baggethun, et al., 2013). First, urban environments face unique hurdles pertaining to heat load due to the urban heat island effect, which causes urban environments to exhibit higher temperatures than non-urban area in the same natural environment. The urban heat island effect is widely due to city surfaces absorbing more heat, and temperatures are further increased by cities producing heat from human activities. Trees reduce the effects of the urban heat island effect by intercepting light that would otherwise reach more absorbent city surfaces, and being able to dissipate that heat much efficiently. (Bowler D. E., Buyung-Ali, Knight, & Pullin, 2010). This results in lower high and average temperatures of air and city surfaces in areas with urban forests (Livesley, McPherson, & Calfapietra, 2016). A secondary effect of trees intercepting light is reduced exposure to ultraviolet radiation in forested urban areas (Heisler, Grant, & Gao, 2003). Urban trees also help intercept rainfall reducing runoff, reduce soil erosion, and increase urban capacity to handle flooding by storing water and improving surrounding soils' ability to take in and store water (Xiao & McPherson, 2002) (Vico, Revelli, & Porporato, 2014). Furthermore, urban forests help reduce air pollution and improve overall air quality, reducing risk of related complications such as from asthma. There have been some concerns about potential dangers of pollen emission to those susceptible, but with careful planning of urban forests, this risk can be minimized. (Nowak, Hirabayashi, Doyle, McGovern, & Pasher, 2018)

Supporting habitat services of urban forests are harder to quantify tangible benefits to, as ultimately their value to a community is determined subjectively by the importance of wildlife to members of that community. This in addition to urban ecosystems having significantly different wildlife makeups and dynamics with animal movement make broadly applicable research scarce. Successful models have been produced to factor wildlife habitat and resources available to naturally maintain populations, however most available models pertain to migratory birds, and seasonal cover or nesting (Lerman, Nislow, & Nowak, 2014). Ultimately, supporting habitat is not an area of urban forestry that broad knowledge can be applied across the board, and requires knowledge not only of urban ecosystem dynamics, but community values in priorities for urban landscapes.

Finally, Urban forests also contribute to the culture of areas they inhabit. Cultural services in the context of urban forests are defined by their recreational value, aesthetic benefits, and benefits to the community dynamics of their neighborhoods. Quantifiably, areas with great urban canopy exhibit lower rates of violent and property crime (Gilstad-Hayden, et al., 2015), increased ability to cope with stress (Kühn, et al., 2017), as well as decreases in depression and anxiety in well forested neighborhoods (Beyer, et al., 2014). While urban forests clearly have a significant effect on individuals, more densely forested neighborhoods also report stronger sense of community (Holtan, Dieterlen, & Sullivan, 2014). Additionally, urban forests with higher species richness show evidence of supporting the mental well-being of inhabitants to a greater degree than environments with low biodiversity (Wolf, Balmford, White, & Weinstein, 2017) Additionally, urban forests play a role in carving out a community's home, with urban forests reportedly easing transitions into new countries for migrants, allowing for recreational space that has potential to transcend language barriers. It is important to note however that these results are limited to a finite subset of cultures studied, and may not be universally applicable (Jay & Schraml, 2009).

It is important to note that Urban forest health is not a given. Urban forests are investments by municipalities, and maintaining their health is just as important as the benefits they yield when healthy. Urban forests increase a city's resilience to climate change (Rosenzweig & Solecki, 2010), and improve many aspects of life in the city, but these forests themselves need to be resilient if they're to provide ecosystem services to their city reliably. In recent years, many cities have adopted urban ecosystem frameworks that plan to provide urban ecosystem services, but neglect many other important considerations, such as integrating landscape with urban planning, and managing for forest resilience (Boyd, 2015). To better plan around these potential downfalls in urban forest planning, urban forests must be planned, designed and managed using ecological frameworks, and cities need to ensure that that ecosystem services they're planning to develop are resilient and able to weather current and future conditions. (McPhearson, Andersson, Elmqvist, & Frantzeskaki, 2014). Ecological planning of urban forests requires not only looking at the benefits urban forests provide us, but their needs, while keeping this framework within a manageable scope.

Largely, the two goals, derived from ecological approaches to urban forestry are to plan for benefit of urban dwellers and biodiversity. Urban forests are managed to benefit people, however, largely the quality of those ecosystems improves with increasing biodiversity. (Niemlä, Breuste, Guntenspergen, James, & McIntyre, 2011). Diversity largely is characterized by having a high number of appropriate species (species diversity) and keeping relative abundances of species similar (abundance). This prevents a few species from dominating an ecosystem, safeguarding against a potentially large change to that system, should something negatively impact a species of high abundance. In this sense, an urban forest with high diversity (as characterized above) is able to compensate for fluctuations of individual species without compromising the services the ecosystem provides the city (McPhearson, Andersson, Elmqvist, & Frantzeskaki, 2014). This raises an issue, as at both city and neighborhood scales, cities demonstrate low diversity compared to non-urban forests merely in species abundance. Cities demonstrate higher rates of homogeneity in tree species, and especially so at smaller scales, which can in part be attributed to neighborhood urban forest planning focused on areas heavy in one species, such one block or neighborhood being near exclusively one species. (Nock, Paquette, Follett, Nowak, & Messier, 2013). While these trends are potentially harmful to urban forests naturally, however, a number of factors compound the harms these trends could give way to. Climate change is altering climates worldwide, and altering the conditions trees must endure, often hindering their ability to stay healthy (Tubby & Webber, 2010). A more financially and diplomatically connected world also makes delivery of non-native diseases and pests more likely, while climate change may often allow these diseases and pests to spread outside their standard ranges (Tubby & Webber, 2010)

Climate change is a pervasive issue that all ecological matters need to consider when planning for the future. Over the next 30 years 99% of major cities nationwide will experience significant shifts in their climates, 77% of which will shift to that of a city we have a current analogue for, with the remaining 22% experiencing shifts that do not mirror that of any location we have a current analogue for (Bastin, et al., 2019). The effects of climate change and changing conditions in areas vs their historic climates, species distribution models based on climate predict the need for wholesale redistribution of tree species over the next century (Malcom, Markham, Neilson, & Oaraci, 2002). This prediction pertains to all tree species in natural or manufactured environments, however, urban ecosystem ecology significantly changes how applicable this prediction is. In predicting a trend of migration of tree species, three methods by which this shift in tree species composition will occur were put forth, those being adaptation (species populations adapt by evolving to continue thriving in their current environments), migration (species will continue to colonize areas as their corresponding climate conditions facilitate their survival) or extirpation (species will be unable to colonize along climate gradient or adapt quickly enough to persist). As a result, to widely maintain biodiversity and keep ecosystems resilient, some species, particularly those with small populations or facing declines due to fragmented ranges, low reproduction, or suffering from introduced insects or diseases may need their migration facilitated via human intervention (Aitken, Yeaman, Holliday, Wang, & Sierra, 2008). There exists a lack of conclusive empirical data pertaining to natural forests ability to adapt to the rapidly changing climate through evolution, concluding that it is feasible, but has not been demonstrated yet in a formal study (Aitken, Yeaman, Holliday, Wang, & Sierra, 2008). The key distinction between natural forests and urban forests is gene flow and the ability to evolve via natural selection. Gene flow in urban areas, particularly in trees is the result of human selection and planning, resulting in non-adaptive evolution (Miles, Rivkin, Johnson, Munshi-South, & Verrelli, 2019). Evolution in this manner does not result in evolution to best survive and reproduce in an environment, meaning urban tree populations do not adapt to their environmental conditions such as climate, pests and pathogens in the same way that natural forests do (Miles, Rivkin, Johnson, Munshi-South, & Verrelli, 2019).

To keep urban forests healthy, we must consider not only the benefits of the trees to the city, but how those trees fit into, and enrich the ecosystem there. This involves taking into account an increasingly long list of factors such as planning redundancies in benefits between multiple species such that threats to one will impact the total function of the ecosystem significantly less (Hale, Pugh, Sadler, & al., 2015). Many things complicate this however, such as planning for the current and future projected climate conditions of an area, and the myriad of urban considerations such as traffic flow, and budget constraints (Hale, Pugh, Sadler, & al., 2015).

Redundancy in ecosystem function via species diversity is one of the greatest tools in securing healthy urban ecosystem function and services as we combat two rising threats to urban ecosystem health: climate change, and invasive pests and diseases (Hale, Pugh, Sadler, & al., 2015). One such example of potential dangers of invasive pests and the modern climate is emerald ash borer.

Emerald ash borer

Emerald ash borer, or EAB for short is a pest native to eastern Asia that in recent decades has escaped its native range, with locations in North America and Europe experiencing growing populations of the pest (Haack, et al., 2002). In EAB's native range, Asian varieties of ash trees have evolved to deal with it, generally only being seriously harmed by the pests during particularly stressful periods or conditions, such as prolonged droughts, or more human issues such as soil compaction from construction. (Zhang, Huang, Zho, & Liu, 2005) European and American species of ash haven't coevolved with EAB however, making its sudden introduction deadly to these trees, exhibiting fatality rates of near 100% if left untreated (National Parks Service, 2017). Not only is EAB incredibly dangerous to trees it infects, but its reproduction, combined with human activities pertaining to ash wood use allow it to disperse across large distances, and make it across areas without any host trees. (Driesche & Reardon, 2015)

Emerald ash borer is a serious threat to ash trees in an ever-expanding area in the United States, but not as adults. Adult emerald ash borers pose little immediate risk to their associated host, Adult EAB are only a minor inconvenience to most healthy ash trees, as adults feed near exclusively on ash leaves. Most healthy trees can deal with some defoliation without significantly hindering the plant considerably. The danger of EAB to ash doesn't come from adult feeding, but how EAB rears their young. After using pheromones to locate a mate, EAB lay their eggs on or under the folds of ash bark. Once these eggs reach maturity, the larvae will eat through the side of the egg facing the tree and continue to burrow in until they reach the phloem layer of the tree (the nutrient rich layer under the bark that transports sugars within the tree). By essentially intercepting and eating the tree's food, EAB can devastate an ill-adapted tree, healthy or struggling. While this method, when compounded with multiple pests and reproduction cycles is enough to kill a single ash tree, a much larger concern is born in transporting infected lumber (Driesche & Reardon, 2015).

EAB eggs are only 1/25th of an inch in diameter, and are generally deposited between folds in the bark, making detecting their presence more than difficult to the untrained eye. This makes transporting lumber, be it for firewood or building, a potential act of environmental destruction if infected ash wood is delivered to uncolonized woods. There are safe ways to transport ash wood however, it has been shown that if the bark and outer wood layer of a log is removed (EAB larvae reside in the inner bark, but can burrow slightly deeper) the wood becomes safe to transport without fear of spread (Liu, 2018). EAB is much harder to maintain than simply avoiding the transport of ash wood however, it has also been demonstrated that EAB will hitchhike on peoples' clothes, or even on cars to find suitable hosts. The effects of this "hitchhiking" behavior can be seen in the vastly increased spread of EAB along major highways, even in areas with bans on the transportation of ash wood (Buck & Marshall, 2008).

In a majority of US areas with significant ash resources however, EAB has already moved in (see figure 1). Treatment of EAB in an area is complex, and requires cooperation between many groups handling natural resources, and many steps and moving parts to work effectively. A study postulating 4 broad categories of EAB response was published in the Journal of Integrated Pest Management specifically on what is needed to execute control measures, their benefits, and how to identify which general strategies and objectives fit your community's needs. While one of these plans is to merely do nothing, two of the other three involve significant removal of ash resources (one being a total removal of urban ash), and the final being an aggressive and ongoing care regimen for all ash resources in the area (Liu, 2018). Orchestrating large sweeping EAB response is not the objective of this study however. Through both understanding integrated approaches, and non-integrated municipal approaches engineered in response to existing ash resources (Hauer & Peterson, 2017), it has become apparent that we will lose much of our ash resources in EAB infested areas. The objective of this study is not how to prevent this however, but to devise the most widely beneficial and considerate planting suggestions for these empty spaces left in cities and yards, and to recognize the shortcomings of urban forest design that led to EAB causing such profound damage to urban ecosystems.

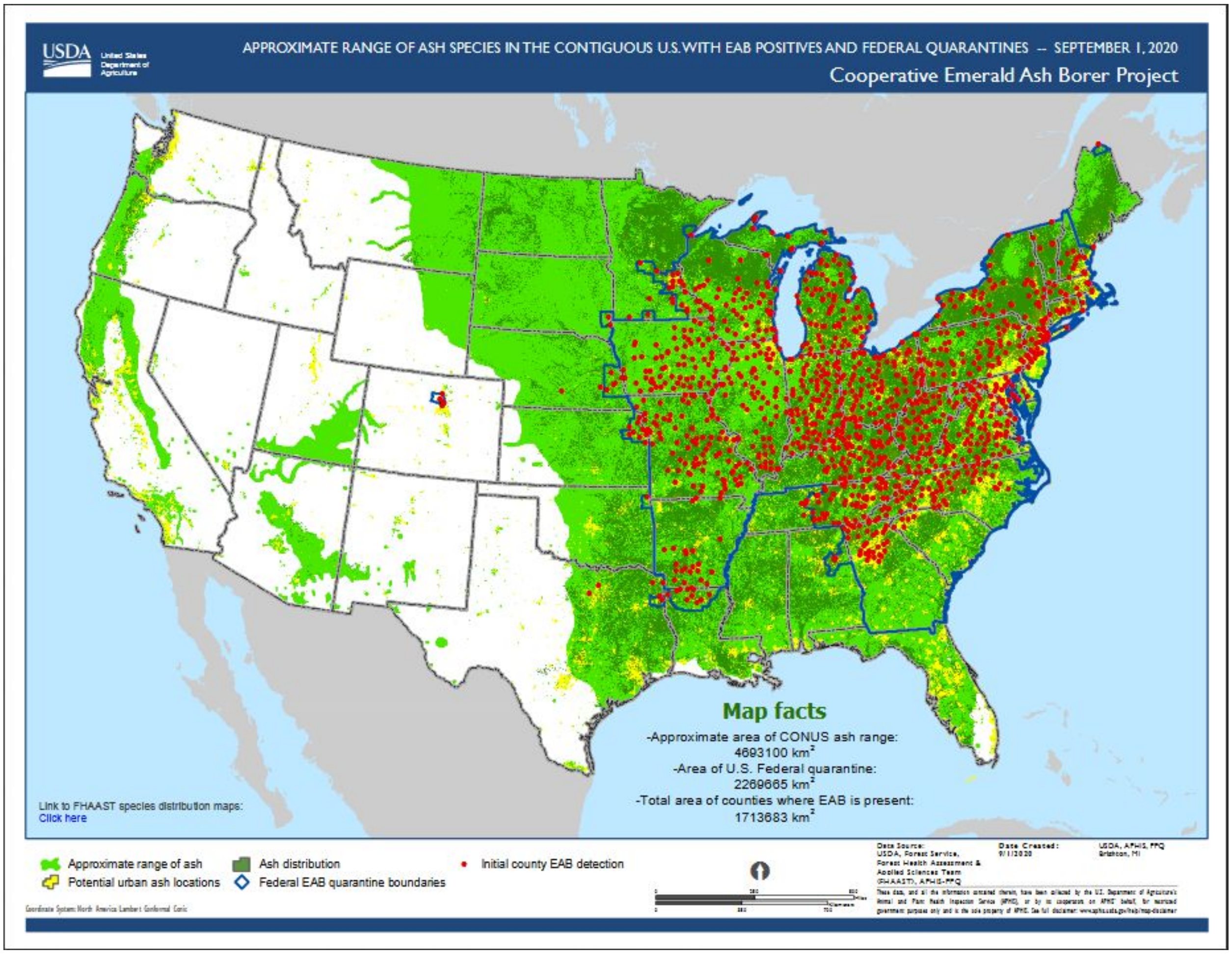

Figure 1: Confirmed EAB detected sites and quarantine area mapped over native ash ranges and distribution of existing ash resources. As discussed in EAB hitchhiking, EAB has established far from the greater population center (United States Department of Agriculture, 2020)

The future of urban forestry

The threat of emerald ash borer is undeniable, but ultimately not an isolated incident. The increased risk of invasive pests and diseases is 3-fold, and is only getting worse with time. First, as the climate changes, the potential ranges for invasive pests expands, putting more trees and more cities at risk should these invasive threats be realized (Tubby & Webber, 2010). Additionally, due to shifting climate conditions, many trees are in climate conditions they are not well adapted to, generally lowering their health and ability to fight off pests, invasive or otherwise (Tubby & Webber, 2010). Lastly, as economies and cultures shift more towards globalization, the risk of invasive species of all sorts increases, meaning instances of invasive pests will become more frequent and expensive if not planned for (Keller, Cadotte, & Sandiford, 2014).

The most beneficial way to break up diversity in trees, particularly for safety of urban forests from sweeping damage due to invasive pests, is by genus (Driesche & Hoddle, 2016). For this reason, for constructing urban forests that are the best able to weather invasive pests, diversity needs to focus on diversity between genera (an example of a genus would be maple or ash, *Acer* and *Fraxinus* respectively).

So, how can all of these factors be accounted for broadly for specific regions? Wide recommendations break down beyond ecological concepts like species diversity and richness, planned redundancy, as well as planning for future climates instead of those areas have historically operated under (Salmond, et al., 2016). Ultimately, research is needed for the climate frameworks municipalities will be functioning under in the near and distant future. Luckily, a number of online tools project this, with some allowing users to choose which climate change model to use, and ranges for dates to deliver data for (such as what city’s current climate another city may resemble in 2060). Sister city tools are relatively limited in the data they return when planning urban forests however. Most cities have some form of publicly available list of trees approved for planting by city officials, or local nurseries may have stock listed or have guidance for local tree planting. Other options for getting tree planting lists include contacting university extension offices or similar natural resource oriented public outreach efforts near the target city, or contacting state or federal agencies such as the NRD. The USDA's PLANTS database can be used to read more about potential tree selection, benefits it may provide, care or site considerations.

All the above recommendations can yield results regardless of those searching, but what to do with that information will widely depend on who is using it. For municipalities, many steps follow from this pertaining to discussing goals of the urban forest landscape, ecosystem services, projected maintenance, space, costs, etc. For those merely looking to select a yard tree or landscape their yards, planting lists will give some ideas for potential trees, and further research into listed trees may give home/property owners a better idea of how different trees may serve their needs. Ultimately, similar guidelines for staying away from abundant tree species or genera do apply, and can help the owner feel safe in their selections and those trees longevity given increasing threats to trees (Tubby & Webber, 2010).

Beyond selecting tree species to plant, locating distributors may prove difficult. Nursery stock is variable throughout areas, and often forward-looking species may be difficult to find (Williams & Dumroese, 2014). For this reason, it is important to locate a nursery that is knowledgeable on industry standards and research. This will ensure that nursery stock is of high quality, and increase the chances that forward-looking stock is available. Nurseries that supply municipalities generally produce quality stock, and carry a significant array of species (Burcham & Lyons, 2013). As tree stock does take a number of years to produce, it is worth noting that many forward-looking trees may be younger and smaller (Burcham & Lyons, 2013). While the nursery industry is a crucial part of creating diverse and resilient urban forests, there is a significant amount of observed lag between industry standards and scientific research and nursery action and available stock (Williams & Dumroese, 2014). Ultimately, until nursery practices catch up with current science across the board, the most direct action that can be taken to ensure diverse and forward-looking stock is to petition reputable nurseries for certain species. The larger numbers and greater business ensured if that stock is picked up, the more likely stock may be added. This may be done through partnerships with neighborhood associations, homeowners' associations, businesses, etc.

Conclusion and closing thoughts

In the wake of an invasive pest introduction that's shown the United States just how fragile low diversity urban forests are, it is important that urban planning take up more integrated and forward thinking approaches to urban forestry. Existing trees will only lose vigor in fighting off disease, pests, and other disturbances as the climate continues to change (Tubby & Webber, 2010), so we need to plan our urban ecosystems with an eye to the future in many ways. Tree diversity in urban areas needs human assistance in migrating with the climate (Malcom, Markham, Neilson, & Oaraci, 2002), and that migration needs to be planned such that one genus is not supplying a disproportionate load of ecosystem services. Tools, such as UNL Extension's Climate4Cities sister city tool (https://hprcc.unl.edu/climate4cities/sister.php), and the University of Maryland's center of environmental science's app for predicting city climates in 60 years (https://www.umces.edu/futureurbanclimates) are invaluable in making the transition to more diverse, resilient, and servicing urban forests a more accessible endeavor.

In closing, while it is easy to see the good transitioning towards these planning strategies could provide, it is always important to remember equitable implementation. In cities across the United States, there already exists disparities in urban forest canopy cover, and maintenance investment between high- and low-income neighborhoods (Schwarz, et al., 2015), which follows that low-income citizens enjoy far fewer benefits of urban forests, further compounding struggles of low income areas (Gilstad-Hayden, et al., 2015) (Kühn, et al., 2017). Equitable forests are a positive step in tackling systemic disparities in cities.

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