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Urban Forests and Their Potential to Combat Food Insecurity: Analyzing Street Trees in Baltimore, MD for Their Edibility

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ABSTRACT

Food insecure environments, in which residents lack consistent access to nutritious food materials, can occur in urban settings. Literature on urban forests suggests that trees can provide a range of provisioning ecosystem services, including edible uses. We consider this to determine if street trees in Baltimore, Maryland have the potential to provide nutritious food materials to address food insecurity in Healthy Food Priority Areas (HFPA), designated by Johns Hopkins Center for a Liveable Future. Our analysis utilizes the *Plants For a Future* database and the geospatial hotspot analysis tool in Esri's ArcMap to determine the edible quality ratings (EQR) of street tree species and where these species cluster in the city in relation to the HFPA. The preliminary spatial analysis reveals 340 total species of street trees, of which 90 (26.5%) have an EQR of 3 or greater. Our analysis found 20,347 (16.71%) of the 121,744 street trees that have an EQR of 3 or greater in clustered hotspots, and 3,033 (2.49%) of these trees are in designated HFPA. The street trees clustered in these hotspots can contribute to providing healthful food to HFPA communities, but our analysis suggests that these trees will not significantly contribute to combatting food insecurity.

INTRODUCTION

Recent literature has emphasized the importance of the urban forest towards creating interactions to nature for urban residents. These greenspaces (eg. parks, cemeteries, campus, street trees) include publicly and privately owned urban trees, shrubs, and herbaceous species that provide opportunities for urban residents to interact with nature and utilize their benefits, or ecosystem services (Nowak et al 2010). These services can contribute to reducing the urban heat island, utilizing species for cultural significance, air regulation, habitat, and provisioning services such as using their edible components (Hurley and Emery 2018, Hurley et al 2022). Food insecurity, as defined by the USDA, is the limited or uncertain availability of nutritionally adequate and safe foods or limited or uncertain ability to access acceptable foods (2021). Previous studies connect the provision of food by the urban forest and the potential of alleviating food insecurity in cities (Clark and Nicholas 2013, Synk et al 2017, Bunge et al 2019), but the potential of the existing urban forest and its food materials to contribute to a United States city's diet has not been analyzed.

This study examines the potential that street trees located in Baltimore, Maryland have towards creating access to edible materials that can contribute towards increasing food security. To do this, I utilize multiple databases and inventories to create spatial analysis maps using Esri's ArcMap to understand the composition and distribution of taxa through the perspective of accessible food materials in relation to food insecure communities in Baltimore. We draw on previous studies to understand edible desirability and the location and identification of food insecure areas, or Healthy Food Priority Areas (HFPAs) (Hurley and Emery 2018, Hurley et al 2022, Misiaszek et al 2018). These databases include the Baltimore Parks and Recreations street tree inventory, which features species information relating to identification, location, abundance, and diversity of taxa in the city; and the *Plants For a Future* (PFAF) database, which provides the edible materials each taxa in the city has and designates each taxa with an edible quality rating (EQR), where a rating of “3” or greater indicates desirability of edible products. Using the information from these datasets, hot spot analysis can be used to spatially analyze the street tree inventory based on where highly rated taxa, or those with an EQR of “3” or greater, cluster in the city. These maps are used to analyze the accessibility of food materials in the urban ecosystem in relation to food insecure areas identified in the city based on where overlap is with clusters of highly rated edible taxa. Due to differences in seasonal availability of food materials derived from plants, we took our analysis one step further to identify the seasonality of the taxa in Baltimore to understand the access residents have throughout the year by performing the same methodology.

This analysis reveals that there are a range of food materials that can be accessible through Baltimore’s street trees, where almost half of the street tree abundance is highly rated for edible quality. Some taxa in the city can provide up to three edible materials, including blossoms, fruits, leaves, and seeds. When comparing the overlap of trees that have a higher quality rating to the HFPAs, our results suggest that there are some areas that have greater access than others to these materials. The seasonality analysis suggests that fall is the most accessible season based on tree abundance. This analysis can inform management decisions relating to taxa composition, stewardship, rules relating to harvest, and increasing biodiversity.

LITERATURE REVIEW

2.1 Urban Ecosystem Services, Urban Forests, and Foraging

Cities are home to ecological systems that provide diverse benefits, or ecosystem services, for urban residents (Shackleton et al. 2017, Hurley & Emery 2018, McLain et al. 2013). These ecosystems benefits fall into several distinct categories, including regulating services such as air pollution removal, carbon storage and sequestration, and stormwater capture (Nowak et al 2016), cultural services such as contribution to cultural identity, sense of belonging, and wellbeing (Kaoma and Shackleton 2014), and supporting services contributing to enhancing biodiversity (Hurley and Emery 2018). Research on these ecosystems and the services they provide typically examines the relationship between residents and the extent to which residents experience their benefits.

Previous studies have shown that key interactions with nature for urban residents occur in the many diverse places, of distinct greenspaces (e.g., parks, cemeteries, campuses, rights-of-way along roads, street trees) that include elements of the urban forest. The urban forest is comprised of urban trees, shrubs, and herbaceous species, publicly or privately owned, that provide a range of services that affect the city's physical and social environments while enhancing quality of life (Nowak et al 2010). In terms of the specific ecosystem services derived from urban forests, the many species of plants that comprise these ecosystems can be accessed and used for the benefits, or the provisioning services, they create (Hurley and Emery 2018, Hurley et al 2022). There is a developing movement to increase edible green infrastructure in cities, which involves the concept of a sustainable planned network of edible food components and structures within the urban ecosystem which are managed and designed to provide primarily provisioning ecosystem services (Russo et al 2017). This infrastructure includes greenspaces such as allotment gardens, rooftop gardening, edible landscaping, and urban forests (Russo et al 2017). The benefits and aims derived from edible green infrastructure include focuses on improving food security, creating sustainable social interactions, urban regeneration, tourism, education, crime reduction, and more (Russo and Cirella 2020). Edible green infrastructure also provides opportunity for residents to create community involving multiple sociocultural groups surrounding the education and awareness of food provision and access (Fischer et al 2019).

Provisioning services are also analyzed through urban food forestry, which is the use of woody perennial food producing species in urban edible landscapes with the intention to improve the sustainability and resilience of urban communities (Clark and Nicholas 2013; Bukowski and Munsell 2018). All food forests are unique, but most focus on the critical concepts of environment and society because of their influence in actions such as planning, planting, and maintenance of the space (Bukowski and Munsell 2018). There are many initiatives surrounding the practice of urban food forestry, but most of the projects engage with at least one of these three initiatives; harvesting, planting, and mapping. By establishing food trees with community members through planting, mapping their existence, and making use of their produce by harvesting, these initiatives seek to create connections between urban residents and spaces that are intentionally designed to produce food, thereby providing access to nutrient dense foods in areas that are managed for their edible landscaping (Clark and Nicholas 2013).

To better understand the benefits that residents actually derive from urban ecosystems, particularly when it comes to provisioning ecosystem services, scholars analyze the practice of foraging. Foraging refers to residents who harvest or gather raw biological resources that they did not plant or cultivate (Shackleton et al 2017, Bunge et al 2019). In these spaces, foragers may find a range of different materials from both native and nonnative species, including fruits, berries, nuts, flowers, blossoms, and leaves, that they incorporate into their daily lives (McLain et al. 2013; Poe et al. 2013, 2014; Hurley et al. 2015; Hurley and Emery 2018). Research on foraging practices has documented the ways these harvests support livelihoods; provide foods, medicines, and other materials for use; and provide opportunities for residents to connect to and enhance their relationships with nature (Poe et al 2014; Fischer and Kowarik 2020; Landor-Yamagata 2017). As the field has matured, studies have sought to better understand how foraging may meet the needs for residents. In Baltimore, surveys were given to foragers to quantify foraging practices to understand the material benefits the urban forest was providing to residents, including dietary contributions (Synk et al 2017).

While many of the studies above focus on foraging in the United States, multiple studies from other countries and continents document the benefits of this practice in the urban forest. In South Africa, foraging is examined as a tool for food provision that provides widespread access to a variety of demographics with positive attitudes towards the practice (Garekae and Shackleton 2020). Foraging in the British Isles has been a practice for centuries and has increased in popularity through the years (Luczaj et al 2021), and in Vienna, wild food foraging is supported by initiatives such as guided hikes in urban green spaces and brochures providing foraging information (Schunko et al 2021). In India, urban foraging is a promising approach towards nature connectedness while developing knowledge on climate resilient food habits and biodiverse greenspaces (Dhyani and Kadaverugu 2020), and in Bengaluru City, there is a demand for foraged species either by participating the practice or by purchasing the materials (Somesh et al 2021). Still, much of the urban foraging literature focuses on species composition and what is used, or the foragers and how they understand the practice (Shackleton et al 2017).

Like the research on urban food forestry, some studies of the existing urban forest and its relationship to foraging have sought to understand the alignment (or not) of the existing urban forest and the types of items that foragers seek and whether these occur in amounts to meet foraging demand. In New York City, tree species were analyzed to determine potential sources of provisioning services by quantifying the availability of materials in relation to abundance of uses, location, and desirability (edible, medicinal, and other) of tree species in the city (Hurley and Emery 2018). By contrast, research in Syracuse has examined the abundance of desirable species, analyzing the potential of these species to contribute to urban nutrition, food security, and food sovereignty by examining the yields of common food producing urban trees (Bunge et al 2019). To date, however, no existing study yet has analyzed the full suite of foods that are present within existing urban forests (i.e. species composition of the urban forest for a specific city), differences in the abundance of species according to their edibility or desirability across the city, and which of these species are generally accessible to residents (i.e. street trees).

2.2 Food Insecurity

Food insecurity is defined as the limited or uncertain availability of nutritionally adequate and safe foods or limited or uncertain ability to access acceptable foods (USDA 2021). Studies examining access often focus on travel distance to a grocery store, availability of culturally important foods, and price differences with nutrient dense foods compared to energy dense foods (Misiaszek et al 2018; Bunge et al 2019; Clark and Nicholas 2013). This lack of access can lead to many health problems, such as malnutrition, hunger, obesity, diabetes, high blood pressure, and more (Misiaszek et al 2018). Maintaining the food security of rapidly growing urban populations, particularly the poor, is considered by some to be one of the greatest challenges of the 21st century (Clark and Nicholas 2013).

Outside of North America, scholars studying food insecurity have pointed to the ways that wild foods can be used to enhance food security and dietary diversity, providing people with micronutrients and enriching diets (Garekae and Shackleton 2020). For example, food plants in Kampala, Africa have peak seasons based on harvest and play an important role in diet outside of harvest season (Mollee et al 2017). Yet the potential contributions of urban forests for reducing food insecurity has been underexamined, but as indicated above the research on urban food forestry and urban foraging in the United States provides evidence that some community members harvest edible materials from these spaces and share these foods with others, both in food insecure and food secure communities. Indeed, edible urban commons has been suggested to help provide access to food for urban residents facing food insecurity in light of the COVID 19 pandemic, including spaces in the urban forest, community gardens, and public trees (Sardeshpande et al 2020). Urban foraging was perceived positively in South Africa based on the parameters on how it contributed to food security in households in two towns (Garekae and Shackleton 2020), and survey research conducted in Baltimore documented how foragers with an average income of $20k-$40k contribute those materials to their diets three times more than foragers with an income of $100k (Synk et al 2017). In Syracuse, four species were chosen to determine yield availability of these forageable species in relation to food security and showed how this alternative practice is important to an emerging urban food system (Bunge et al 2019). In Burlington Vermont, urban food forestry is introduced as a system that can contribute to improving food security through access of nutrient dense provisioning services (Clark and Nicolas 2013), and in Italy, multiple providences in the Campania region have edible green infrastructure established with projects focusing on dietary health and food productivity (Russo and Cirella 2020).

METHODS

This research analyzes street trees located in Baltimore, Maryland to determine how the distribution of edible species relates to identified food insecure communities in the city. Baltimore is located in central Maryland and has a population of 585,708, making up 92 square miles. The median household income for residents in Baltimore is $52,164, with estimates of 20% of persons in poverty.

To examine this question, I utilize Baltimore's street tree inventory in ESRI's ArcMap 10.7.1. ArcMap is a geographic information system (GIS) program that can be used to explore the spatial distribution of species, together with taxa diversity and the abundance of different taxa. Data from this inventory, including coordinate locations, taxa name, street name, location type, and other notes, was joined to a dataset on useful species created using *Plants for a Future* (PFAF). Following past food access studies, such as Clark and Nicholas (2013), Hurley and Emery (2018), and Hurley et al (2022), I rely on specific information from the PFAF data to better understand ecosystem services, including provisioning services. The PFAF database provides information on over 7,000 species, with individual entries recording physical characteristics, taxa range, edible components, medicinal uses, and cultivation details. This study relies principally on the ratings for edible components for species that were part of the Baltimore street tree inventory. PFAF provides ratings on a 0-5 scale for each species' edible, medicinal, or other value. A rating of "1" designates a species with minor edible uses, while a rating of "5" designates species that have great value for their edible uses (Hurley and Emery 2017, Hurley et al 2022). Following Hurley et al. (2022), I consider highly rated species, or those likely to be harvested by foragers and thus, eaten, to be those species with a rating greater than or equal to three. Some of the taxa in the higher rated inventory have more than one edible component attributed to them, including fruit, leaves, seeds, and flowers. Although PFAF also identifies edible components such as oil, sap, inner bark, and manna, I did not include these materials in my analysis due to difficulty of harvesting these edible items, potentially resulting in damage to the tree, they are not considered as an edible component.

To identify areas of the city that are considered food insecure, I turned to the work of Johns Hopkins Center for a Livable Future and its study of Healthy Food Priority Areas (HFPA). This analysis identifies areas in Baltimore where residents would have difficulty accessing healthy foods (Misiaszek et al 2017), drawing on four factors to define areas of food insecurity and to identify these as HFPAs. The first factor is a Healthy Food Availability Index score of all food stores being categorized as low. This scoring system rates the presence of healthy foods in grocery stores. The range of this score is from 0-28, and a low score ranges from 0-9.5. On this scale, a higher score indicates a greater presence of healthy foods. The second factor is the median household income of the area, or specifically where an area's median household income is equal to or below the federal poverty level. The third factor identifies that 30% of the households in the area lack vehicle availability. The final factor considers the distance to a supermarket, highlighting areas where the distance to a store is more than ¼ mile away from the designated area (Misiaszek et al 2017). A total of 84 areas in Baltimore meet the criteria established by these four factors, which represent the 84 HFPAs I consider in this study.

To analyze the availability of street trees in Baltimore with highly rated species, I used the optimized hotspot analysis tool in ArcMap. This tool identifies statistically significant clusters of high values, or hotspots, and low values, or cold spots, by aggregating the street tree point data into a grid pattern and identifying hot and cold spots based on the proximity of data points with particular attributes. Statistical significance is projected based on confidence intervals that are mapped onto a grid pattern, in which 99% confidence represents the highest confidence in interacting with clusters of trees, then the scale deceases to 95% confidence and 90% confidence. The grid pattern used was 587sqft by 587sqft. Using this tool, I am able to identify places, or hotspots, where people have a high statistical chance of encountering clusters of tree species that have edible materials associated with species whose edible quality ratings are “3” or greater. The hotspots are represented by the red gradient in the analysis. This tool also can identify places where people have a low statistical chance of encounter clusters of these trees with these characteristics, which are represented by the blue gradient. Those grids with tan colors indicate that street trees with these qualities are present in the area, but they are not organized in statistically significant cluster.

To determine if highly rated edible species are accessible in the food insecure areas, or HFPA’s, in Baltimore, I examined the optimized hotspot analysis of tree point data for edible quality ratings of “3,” “4,”, and “5,” both individually and combined, in relation to HFPAs. The combined analysis was specifically analyzed for overlap with the 84 HFPAs (Misiaszek et al 2017). This map is used to count the highly rated street trees in each HFPA hotspot to identify the food insecure areas that have access to the food materials. The analysis considers percent overlap of each HFPA to hotspots, abundance of highly rated trees by EQR, and the total abundance of trees in HFPAs.

Even though species have edible parts attributed to them, these materials are not available year-round. Thus, to explore the seasonal availability of particular food items found in the urban forests in relation to HFPAs, I created a new dataset that includes the seasonal availability of the street trees and their edible parts in Baltimore. Some resources of species information identify seasonality by the actual season, while others do so on a monthly scale. To make sure all data was accounted for, I decided to break down each of the four seasons into an early and late season. If a database classified a species as available in the spring, the species would be classified in both the early and late spring category. The new dataset was added to ArcMap, in which each season was analyzed using the optimized hotspot analysis tool and overlapped with the HFPA dataset. Edible street tree species availability during each season was counted in HFPA hotspots to determine access.

RESULTS

4.1 Street tree inventory – abundance, diversity, distribution

Baltimore's street tree inventory identifies 340 taxa in the city, with a total of 121,744 trees present. However, further analysis of taxa diversity in the Baltimore street tree inventory indicates that 201 of the 340 taxa (59.1%) have less than 30 trees attributed to them, which may lead to conservative results regarding percentage of taxa diversity. Analysis of all 340 tree taxa shows that the most common species found in the city is *Acer rubrum,* with a total of 13,007 (10.68%) trees recorded (Table 1). Table 1 shows the top ten most abundant taxa found in Baltimore, including *Zelkova serrata* (5.57%), *Platanus x acerifolia* (5.01%), and *Tilia cordata* (4.93%) with approximately 5 percent or more of the taxa in the city.

Table 1. Ten Most Abundant Taxa Present in Baltimore Street Tree Inventory. NR designates taxa not rated by the Plants for a Future database.

SPECIES NAME (COMMON NAME)	NUMBER OF TREES	PERCENT OF TREES	EDIBLE QUALITY RATING
Acer rubrum (Northern Red maple)	13007	10.68%	3
*Zelkova serrata (*Japanese zelkova)	6790	5.57%	1
Platanus x acerifolia (London planetree)	6101	5.01%	NR
Tilia cordata (Littleleaf linden)	6002	4.93%	5
Prunus spp. (Cherry/Plum)	5851	4.80%	NR
Pyrus calleryana (Callery pear)	4784	3.92%	2
Acer platanoides (Norway maple)	3790	3.11%	2
Gleditsia triacanthos inermis (Thornless honey locust)	3231	2.65%	NR
Quercus phellos (Willow oak)	3047	2.50%	2
Quercus rubra (Northern red oak)	2857	2.34%	3

4.2 Street tree inventory – edibility and quality ratings

Analysis of taxa diversity in Baltimore based on edible quality ratings shows that taxa with an EQR of “2” are the most abundant in Baltimore, making up 81 of the 340 total taxa (24%) identified in the city. Not rated taxa were the second most abundant, making up 78 of the inventory (23%). Taxa with an EQR of “1” make up 55 taxa of the inventory (16%). Even though street trees with an EQR of “3” are the most abundant, taxa with this rating make up 50 of the total taxa (15%) in Baltimore. Taxa with an EQR of “0” make up 36 of the taxa inventory (11%), and taxa with an EQR of “4” make up 32 of the total taxa present (9%). The least abundant taxa in Baltimore have an EQR of “5”, making up 8 of the total 340 taxa present (2%) in the city (Table 2). The distribution of taxa diversity shows the range that the 340 taxa are spread throughout Baltimore (Figure 1B). Out of the ten most abundant species, 3 are not rated, one has an EQR of “1”, three are rated “2”, two are rated “3” and one is rated “5”.

When examining tree abundance of the street tree composition, the most abundant ratings differed compared to the taxa abundance data. Analysis shows that trees rated as an EQR or “3” have the greatest abundance, with 34,095 trees having this rating (28.01%) in the street tree population (Table 2), while trees with an EQR of “2”, totaling 31,350 of the street trees (25.75%) in the city are the second most abundant. By contrast, trees with an EQR of “5” and “4”, respectfully making up 8,170 (6.71%) and 7,371 (6.05%) of the street tree composition, have some of the lowest abundances. Trees with an EQR of “1” make up 12,450 of the inventory (12.69%), while the least abundant rating in Baltimore includes the street trees with an EQR of “0”, making up only 3,093 of the inventory (2.54%). Trees with no PFAF rating make up 22,215 of the street trees (18.25%). When viewing the inventory spatially, the distribution of tree abundance organized by EQR shows the range that trees with all ratings spread across the city (Figure 1A).

Table 2. Baltimore Street Tree Inventory Classified by Edible Quality Ratings (EQR) with Respect to Abundance and Taxa Diversity.

EDIBLE QUALITY RATING	NUMBER OF TREES	PERCENTAGE OF TREES	NUMBER OF TAXA	PERCENTAGE OF TAXA
5	8,170	6.71%	8	2%
4	7,371	6.05%	32	9%
3	34,095	28.01%	50	15%
2	31,350	25.75%	81	24%
1	15,450	12.69%	55	16%
0	3,093	2.54%	36	11%
NR	22,215	18.25%	78	23%
TOTAL	121,744	100%	340	100%

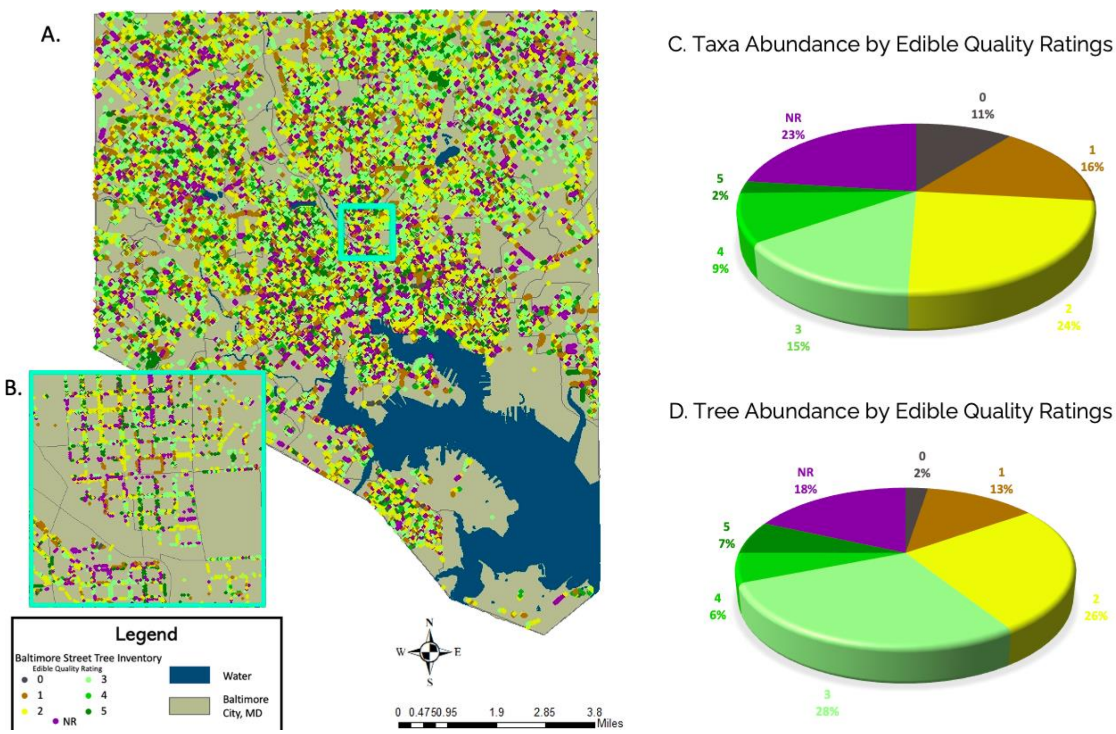


Figure 1. (A) Distribution of Baltimore Street Trees according to Edible Quality Rating of each species. (B) Illustrative 1x1 sq mile area showing distribution. (C) Pie chart analyzing taxa abundance of street tree inventory. (D) Pie chart analyzing tree abundance of street tree inventory.

To determine taxa with desirable edible materials, or those highly rated in terms of their EQR, my analysis only considers species with an EQR ≥ 3, due to their high likelihood of being foraged (Hurley et al 2022, Clark and Nicholas 2013). The Baltimore street tree inventory is comprised of 90 of 340 taxa with these ratings (26.47%), totaling 49,636 of the 121,744 trees (40.77%) in the city (Table 3). When considering the 90 taxa and the corresponding 49,636 highly rated trees, trees with an EQR of "3" are the most diverse taxa (55.5%) and abundant (68.6%), making up 50 of the taxa and 34,095 of the total highly rated inventory. Trees with an EQR of "4" made up 35.5 percent of the taxa in highly rated inventory, but were the least abundant, making up only 14.85 percent of the highly rated trees in the inventory. Even though taxa with an EQR of "5" only represent 8.88 percent of the highly rated taxa, this rating makes up 16.45 percent of the trees in the highly rated inventory.

Table 3. Baltimore Street Tree Inventory Representing Edible Quality Ratings (EQR) ≥ 3 with Respect to Abundance and Taxa Diversity.

EQR	NUMBER OF TREES	PERCENTAGE OF TREES	NUMBER OF TAXA	PERCENTAGE OF TAXA
5	8,170	16.45%	8	8.88%
4	7,371	14.85%	32	35.5%
3	34,095	68.6%	50	55.5%
TOTAL	49,636		90	

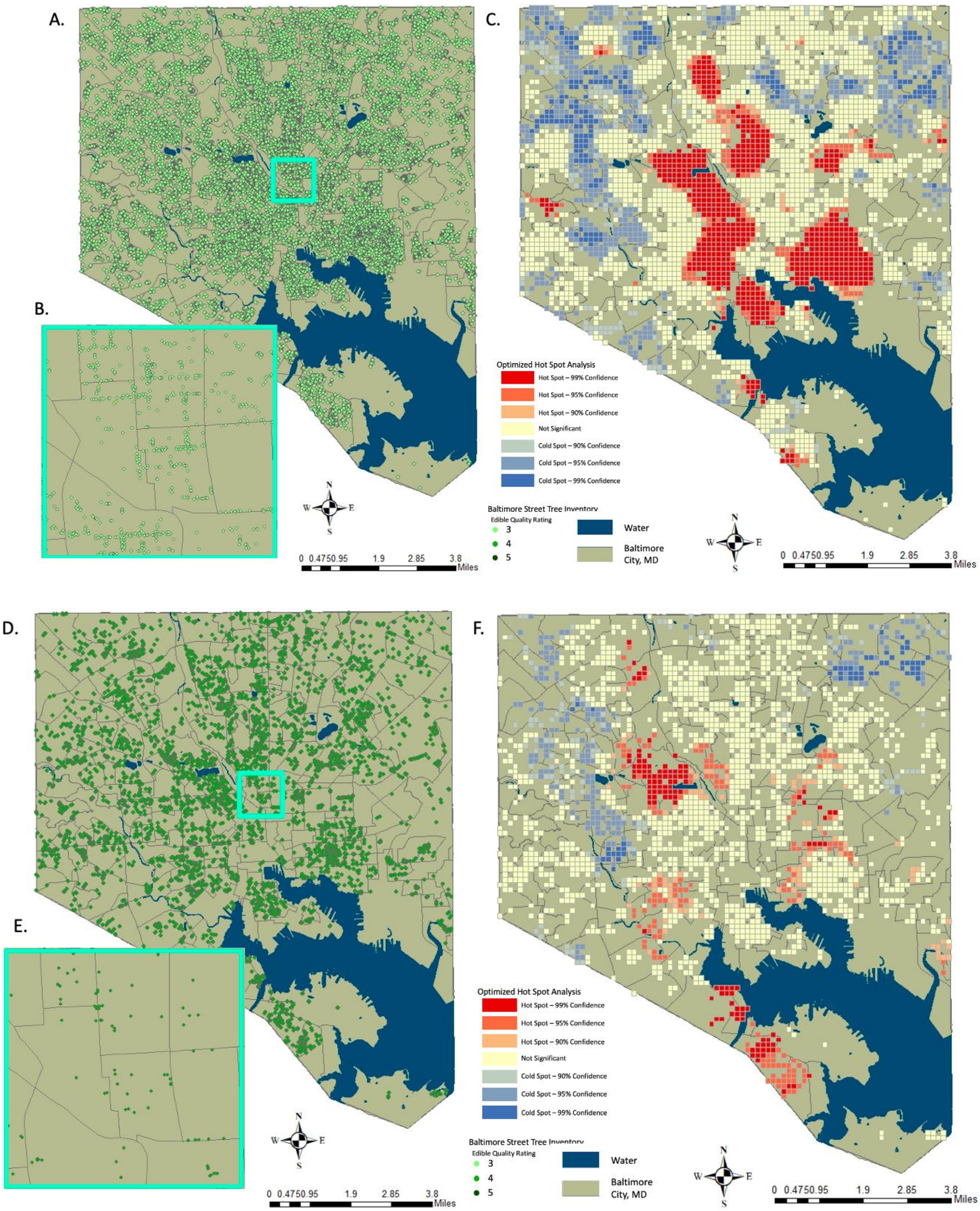
After determining each species' rating, I next examined the edible materials of the higher rated species (Table 4). Taxa with an EQR of "3" have a total of 68 edible materials likely to be harvested. When examining the total number of edible materials attributed to the 50 taxa with and EQR of "3", four have three materials (8%), 14 have two materials (28%), 28 have one material (56%), and four have zero materials (8%). The four taxa with zero materials include taxa that had edible materials not considered in this analysis (e.g., sap, bark). Taxa with an EQR of "4" recorded a total of 47 edible materials. When considering the 32 taxa with an EQR of "4", 20 have one edible material (63%), nine have two edible materials (28%), and three have three materials available (9%). The highest rated taxa, or those taxa with an EQR of "5", have a total of 12 edible materials available. Out of the eight taxa with this rating, five of them have one edible material (63%), two of them had two materials (25%), and one had three materials available (13%).

Table 4. Number of Edible Materials Attributed to Baltimore Street Tree Taxa with Edible Quality Ratings (EQR) ≥ 3.

EQR	ZERO MATERIALS	ONE MATERIAL	TWO MATERIALS	THREE MATERIALS	TOTAL MATERIALS
5	0	5	2	1	12
4	0	20	9	3	47
3	4	28	14	4	68

4.3 Optimized hot spot analysis of street trees rated ≥ 3

Hot spot analysis of street trees according to each of the highly rated street tree ratings revealed the most significant cluster of hot spots in the map was for trees with an EQR of “3” (Figure 2C). The hot spot map produced from this point data shows that trees with this rating are found to be significantly clustered in the center of the city, with cold spots that represent tree presence but significantly not clustered around the outside of the city. Similar clustering, but of a smaller amount, can be seen in the EQR “5” map. Both clusters show hot spots located in the center of the map (Figure 2I). Trees with an EQR of “4” revealed a different pattern in its hot spot map, mostly producing non-significant grids throughout the city with smaller hot spots and cold spots spread around the outer areas of the map (Figure 2F).



A.
B.
C.
Optimized Hot Spot Analysis
Hot Spot – 99% Confidence
Hot Spot – 95% Confidence
Hot Spot – 90% Confidence
Not Significant
Cold Spot – 90% Confidence
Cold Spot – 95% Confidence
Cold Spot – 99% Confidence
Baltimore Street Tree Inventory
Edible Quality Rating
3
4
5
Water
Baltimore City, MD
N
W
E
S
0 0.4750.95 1.9 2.85 3.8 Miles
D.
E.
F.
Optimized Hot Spot Analysis
Hot Spot – 99% Confidence
Hot Spot – 95% Confidence
Hot Spot – 90% Confidence
Not Significant
Cold Spot – 90% Confidence
Cold Spot – 95% Confidence
Cold Spot – 99% Confidence
Baltimore Street Tree Inventory
Edible Quality Rating
3
4
5
Water
Baltimore City, MD
N
W
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0 0.4750.95 1.9 2.85 3.8 Miles

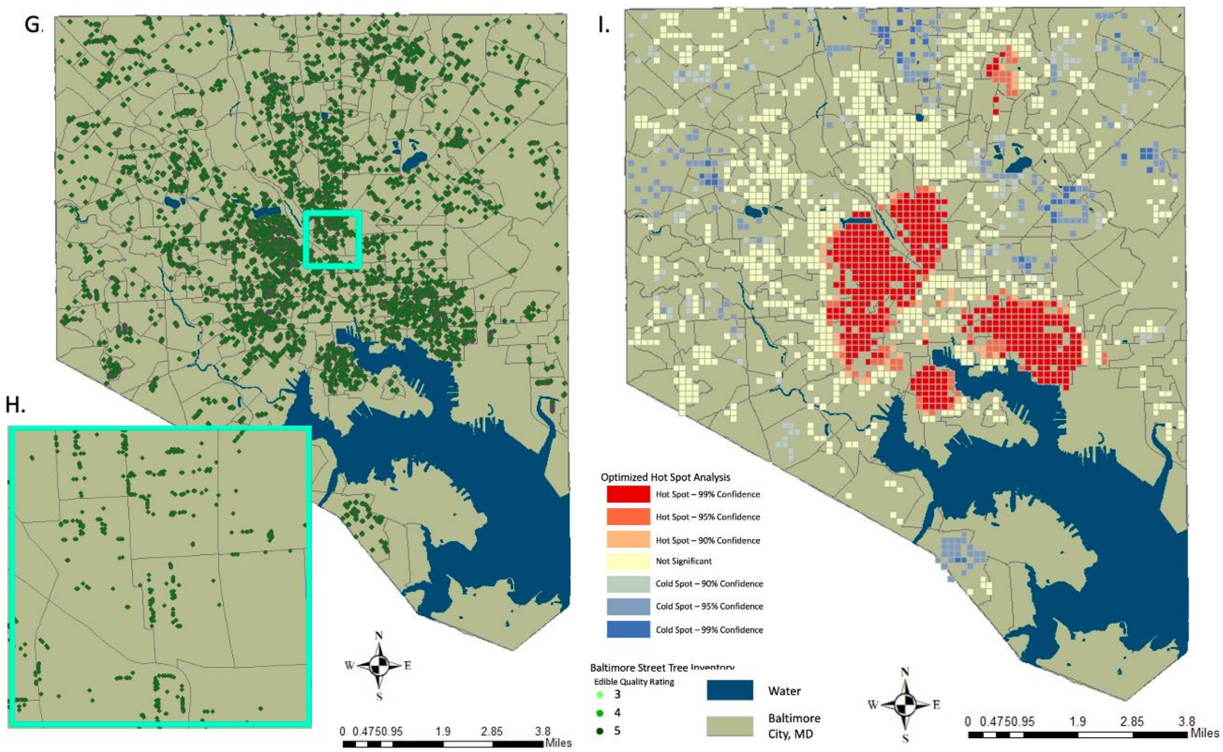


Figure 2. Map of Street Trees Species according to their Edible Quality Ratings. (A) Map of EQR 3 species. (B) Illustrative 1x1 sq mile area showing distribution of EQR 3. (C) Optimized hot spot analysis map of street trees with EQR 3. (D) Map of EQR 4 species. (E) Illustrative 1x1 sq mile area showing distribution of EQR 4. (F) Optimized hot spot analysis map of street trees with EQR 4. (G) Map of EQR 5 species. (H) Illustrative 1x1 sq mile area showing distribution of EQR 5. (I) Optimized hot spot analysis map of street trees with EQR 5.

After conducting analysis of individual EQR clusters, all point data for trees with an EQR of "≥ 3" was combined and analyzed using the optimized hot spot tool to create an aggregated map of highly rated species with edible materials (Figure 3). The emerging hot spot pattern reveals the most significant clustering is in the center of the city, with cold spots surrounding the outside of the map. This pattern is similar to the pattern shown in the EQR "3" individual hot spot map with the majority of the significant grids being present in the center of the map, but the aggregate hot spot results show greater affinity with the patterns found in the separate EQR "4" and EQR "5" maps (Figure 2).

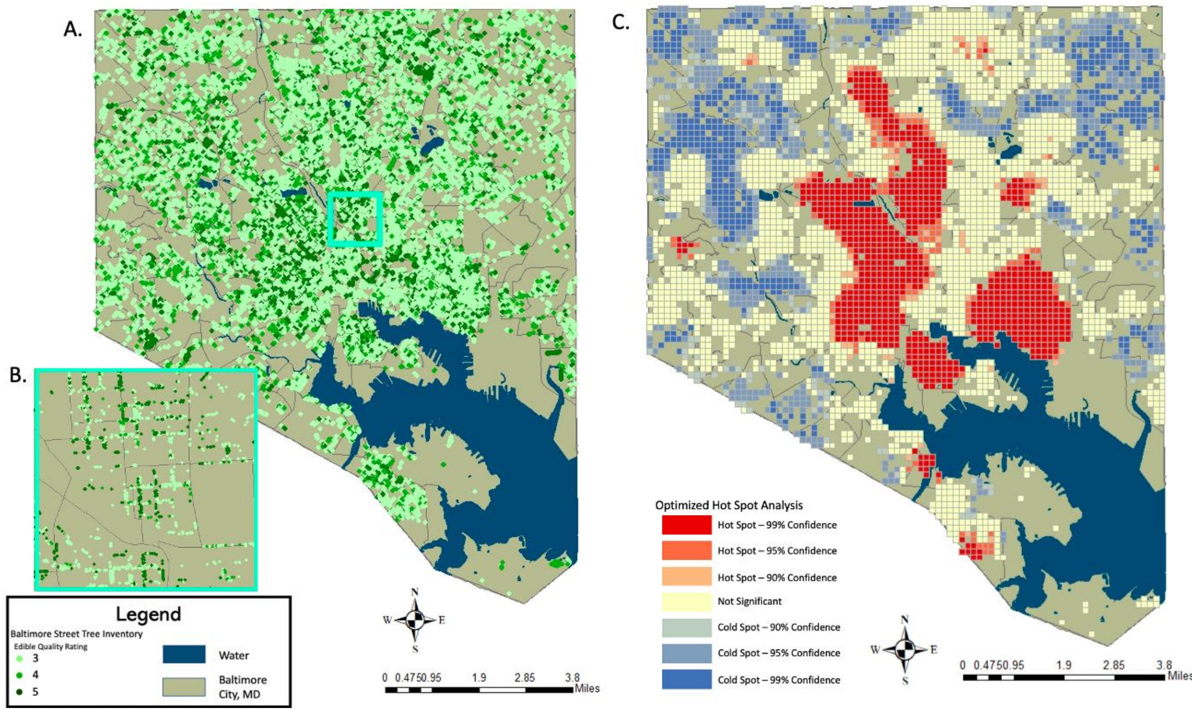


Figure 3. (A) Combined map of street trees with highly rated species. (B) Illustrative 1x1 sq mile area showing distribution. (C) Optimized hot spot analysis map of street trees with Edible Quality Ratings (EQR) ≥ 3.

4.4 Overlap analysis of HFPA and combined hot spot

Analysis of the overlap of hot spots produced by the combined point data of trees with EQR of "≥ 3" and the 84 Healthy Food Priority Areas (HFPA) in our study reveals that HFPA in the center of the city visually has more overlap with hot spots than HFPA in the outside of the city (Figure 4). When considering percent overlap of the two datasets, 13 of the HFPA had 100 percent overlap with the hot spots representing clusters of highly rated trees (15.5%), and 21 of the HFPAs had at least a 50 percent overlap with these hot spots (25%) (Table 5). Overall, there are a total of 30 HFPAs (35.7%) that have at least a one percent overlap with a hot spot, and 54 HFPAs have zero percent overlap with hot spots of highly rated hot spots (64.3%).

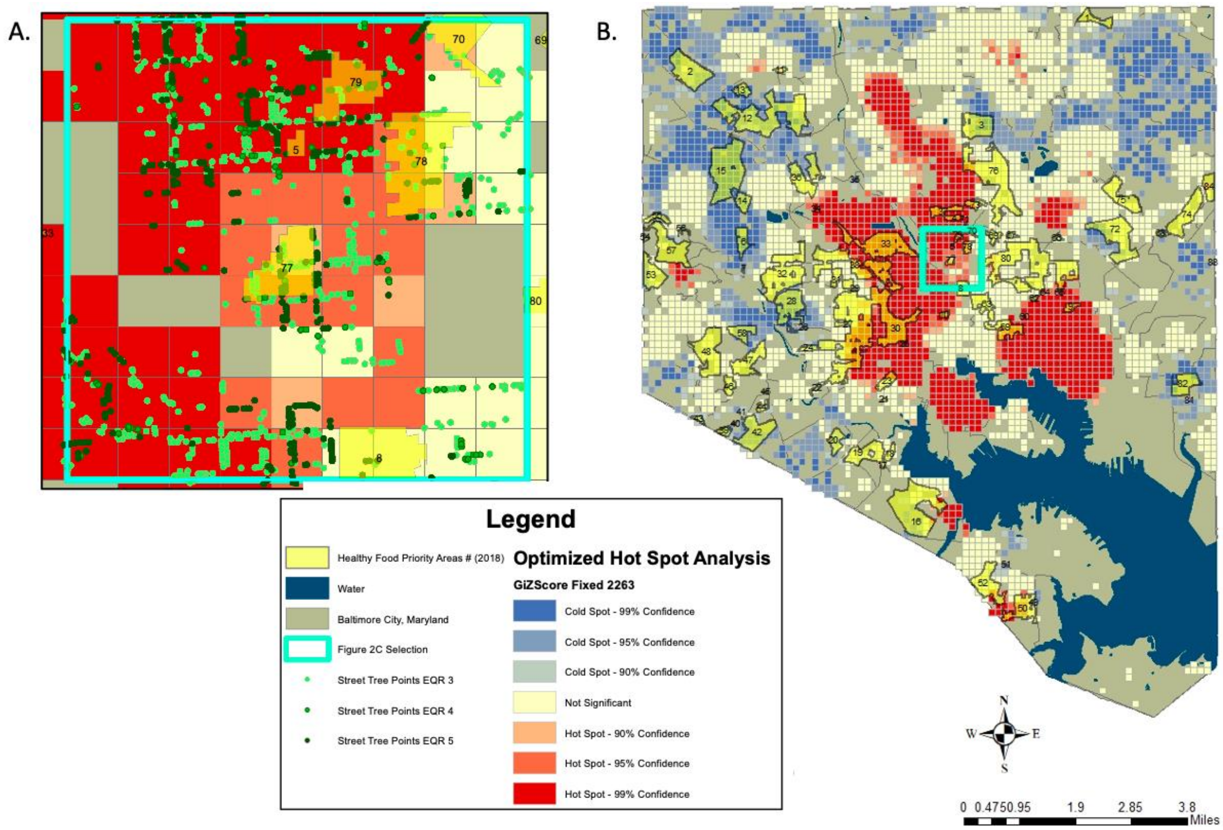


Figure 4. Overlap of Highly Rated Hot Spots and HFPAs in Baltimore, MD.

Given that hot spot analysis is a spatial analysis tool that identifies grids in proximity to other hot spot grids, the results sometimes generate cases where a HFPA visually indicates overlap with a hot spot that does not have any underlying highly rated tree data points present. To address the gaps of the initial analysis, further counts focusing on how many of each desirable EQR was in each HFPA with at least one percent overlap. There are 3,033 trees with a high EQR in the HFPA hot spots. In terms of each EQR, there are a total of 1,835 trees with EQR “3”, 341 with a EQR of “4”, and 857 with an EQR “5” (Table 5). Hot spots are the focus of the overlap study because they indicate a high likelihood of interaction with clusters of highly rated species and indicate the greatest access. This does not mean, however, that the other HFPA areas do not have access to these taxa. Indeed, these areas still have highly rated trees with edible materials, but one is statistically less likely to encounter these trees in those areas.

According to this data, the HFPA with the most edible trees present is HFPA 30, with 968 total trees comprising of 598 EQR “3” trees, 128 EQR “4” trees, and 242 EQR of “5” trees. Some of the HFPA that have 100 percent overlap with edible trees include HFPA 33 with 401 EQR “3” trees, 89 EQR “4” trees, and 312 EQR “5” trees, totaling 802 edible trees and HFPA 37, having 93 EQR “3” trees, 18 EQR “4”, and 36 EQR “5” trees totaling 147 trees (Table 5). HFPA 60 is an example of the overlap consideration, in which the visual overlap analysis indicates the HFPA is 100% overlapped with a hot spot but there are zero trees present in the HFPA.

Table 5. Healthy Food Priority Area overlap with hot spots of highly rated street tree species in Baltimore, Maryland.

% Overlap	HFPA ID #	TOTAL TREES IN HFPA	EQR - 3	EQR - 4	EQR - 5	EDIBLE TREES IN HFPA
100%	4	63	41 (65.08%)	6 (9.52%)	16 (25.39%)	63 (100%)
	5	0	0 (0%)	0 (0%)	0 (0%)	0 (0%)
	9	84	74 (88.10%)	3 (3.57%)	7 (8.33%)	84(100%)
	10	40	38 (95%)	1 (2.5%)	1 (2.5%)	40 (100%)
	25	1	1 (100%)	0 (0%)	0 (0%)	1 (100%)
	34	0	0 (0%)	0 (0%)	0 (0%)	0 (0%)
	37	147	93 (63.27%)	18 (12.24%)	36 (24.49%)	147 (100%)
	60	0	0 (0%)	0 (0%)	0 (0%)	0 (0%)
	61	3	1 (33.33%)	0 (0%)	2 (66.66%)	3 (100%)
	65	2	2 (100%)	0 (0%)	0 (0%)	2 (100%)
	71	3	3 (100%)	0 (0%)	0 (0%)	3 (100%)
	77	53	28 (52.83%)	5 (9.43%)	20 (37.73%)	53 (100%)
	79	22	10 (45.45%)	0 (0%)	12 (54.54%)	22 (100%)
76%-99%	33	802	401 (50%)	89 (11.09%)	312 (38.90%)	802 (100%)
	59	218	95 (43.57%)	2 (0.91%)	63 (28.89%)	160 (73.39%)
	64	1	0 (0%)	0 (0%)	0 (0%)	0 (0%)
	70	3	3 (100%)	0 (0%)	0 (0%)	3 (100%)
	78	29	10 (34.48%)	2 (6.89%)	9 (31.03%)	21 (72.41%)
51%-75%	30	1364	598 (43.84%)	128 (9.38%)	242 (17.74%)	968 (70.97%)
	38	614	280 (45.60%)	52 (8.47%)	119 (19.38%)	451 (73.45%)
	50	43	29 (67.44%)	6 (13.95%)	0 (0%)	35 (81.40%)
26%-50%	23	72	11 (15.27%)	11 (15.27%)	2 (2.77%)	24 (33.33%)
	73	11	6 (54.54%)	1 (9.09%)	0 (0%)	7 (63.64%)
1%-25%	8	23	0 (0%)	0 (0%)	0 (0%)	0 (0%)
	16	104	14 (13.46%)	0 (0%)	0 (0%)	14 (13.46%)
	36	90	0 (0%)	0 (0%)	0 (0%)	0 (0%)
	52	81	7 (8.64%)	2 (2.47%)	0 (0%)	9 (11.11%)
	57	24	0 (0%)	0 (0%)	0 (0%)	0 (0%)
	76	407	18 (4.42%)	3 (0.73%)	1 (0.25%)	22 (5.41%)
	80	636	69 (10.85%)	10 (1.57%)	15 (2.36%)	94 (14.78%)
TOTALS	84	7316	1835	341	857	3033

These data also reveal a total of 36 (40%) taxa are found in the 30 HFPA hot spot overlap areas. Four of the eight tree taxa with an EQR of “5” are present, representing one half of their total taxa found in HFPAs. These taxa include *Gingko biloba*, *Diospyros virginiana*, *Sassafras* *albidum*, and *Tilia cordata*, the fourth most abundant taxa in the inventory. One third of the taxa with an EQR of "4" are present in HFPAs, including the three most abundant taxa in the EQR "4" inventory, *Acer saccharum*, *Quercus bicolor*, and *Morus alba.* Taxa with an EQR of "3" total 21 out of the 50 in HFPA hot spots (66%), including the most abundant taxa in the street tree inventory, *Acer rubrum* (Table 6).

Table 6. Baltimore Street Tree Taxa with EQR ≥ 3 with their Edible Materials. Species and their edible materials are identified using the *Plants for a Future* database. **Bolded** species identify species are found inside HFPA.

Edible Quality Rating 5		*Prunus avium*	fruit, seed	***Cercis canadensis***	**flowers, leaves**
Amelanchier laevis	fruit	***Prunus cerasifera***	**fruit, seed**	*Corylus americana*	oil, seed
Cornus kousa	fruit, leaves	***Prunus serotina***	**fruit, seed**	*Corylus corlurna*	oil, seed
Diospyros virginiana	**fruit, oil**	***Quercus bicolor***	**seed**	***Gleditsia triacanthos***	**seed, seedpod**
Gingko biloba	**oil, seed**	***Quercus prinus***	**seed**	***Gymnocladus dioicus***	**seed, seedpod**
Prunus persica	flowers, fruit, seed	***Quercus robur***	**seed**	*Hovenia dulcis*	fruit
Sassafras albidum	**leaves**	*Rhus copallinum*	fruit, oil	*Juglans cinerea*	oil, sap, seed
Tilia cordata	**leaves, sap**	*Rhus glabra*	fruit, oil, stem	***Juglans nigra***	**oil, sap, seed**
Tilia x europaea	flowers, leaves, manna, sap	*Rhus typhina*	fruit, oil	*Morus rubra*	fruit, leaves
Edible Quality Rating 4		*Sambucus canadensis*	flowers, fruit, leaves	*Myrica cerifera*	fruit
Acer saccharum	**inner bark, leaves, sap, seed**	*Viburnum lentago*	fruit	*Oxydendrum arboreum*	leaves
Aesculus flava	**nectar, seed**	Edible Quality Rating 3		*Pinus bungeana*	seed
Amelanchier canadensis	**fruit**	*Abies balsamea*	inner bark	*Poncirus trifoliata*	fruit, leaves
Asimina triloba	**fruit**	***Acer negundo***	**leaves, sap, seed**	*Prunus americana*	fruit, seed
Broussonetia papyrifera	flowers, fruit, leaves	***Acer rubrum***	**leaves, sap, seed**	*Prunus virginiana*	fruit, seed
Carya illinoinensis	leaves, oil, seed	***Acer saccharinum***	**leaves, sap, seed**	***Quercus alba***	**seed**
Cornus mas	fruit, oil	***Acer x freemanii***		***Quercus lyrata***	**seed**
Crataegus mollis	fruit	***Aesculus hippocastanum***	**seed**	***Quercus macrocarpa***	**seed**
Cryptomeria japonica	leaves, root, stem	*Amelanchier arborea*	fruit	*Quercus muehlenbergii*	seed
Elaeagnus umbellata	fruit, seed	*Betula lenta*	sap	***Quercus palustris***	**seed**
Fagus sylvatica	leaves, oil, seed	***Betula nigra***	**sap**	***Quercus rubra***	**seed**
Ficus carica	fruit, sap	*Betula papyrifera*	flowers, leaves	***Quercus stellata***	**seed**
Hibiscus syriacus	**flowers, leaves, oil, root**	*Betula pendula*	flowers, leaves	*Quercus virginiana*	oil, seed
Juglans regia	oil, sap, seed	*Carya cordiformis*	oil, seed	***Robinia pseudoacacia***	**flowers, seed**
Malus pumila	fruit	*Carya glabra*	sap, seed	*Taxus cuspidate*	fruit
Morus alba	**fruit, leaves**	*Carya laciniosa*	sap, seed	***Tilia americana***	**flowers, leaves**
Musa acuminata	fruit	*Carya ovata*	sap, seed	***Tilia mongolica***	**flowers, leaves**
Pinus koraiensis	oil, seed	*Carya tomentosa*	sap, seed	***Tilia tormentosa***	**flowers, leaves**
Pinus parviflora	seed	*Castanea dentata*	oil, seed	*Viburnum rufidulum*	fruit
Pinus sabiniana	flowers, seed	*Castanea mollissima*	seed	*Xanthoceras sorbifolium*	flowers, leaves, seed
Prunus armeniaca	fruit, seed	***Celtis occidentalis***	**fruit, seed**	*Zanthoxylum piperitum*	fruit, leaves, seed

4.5 Seasonality Analysis

Using PFAF and other plant databases, taxa with an EQR of "≥ 3" were examined to determine the seasonality of the highly rated trees found in Baltimore. There are 90 total taxa with the identifications of an EQR of "≥ 3". Early fall showed to have the most taxa available, making up 53 percent of the highly rated taxa following the late fall results, making up 41 percent of the taxa (Table 7). Out of the 49,636 street trees with this rating, fall showed to have the most abundance with seasonal accessibility, followed by the summer, then the spring. There are a few considerations regarding taxa, such as some taxa being available over multiple seasons. I found that 66 of the 90 total taxa (73.3%) have more than 1 season available, with 2 seasons having the most species with 48 (53.3%).

There were a total of 1,101 trees identified with edible parts available during the winter season. After performing my hotspot analysis, I was able to determine two areas in which there were hot spots that represent significant clusters of trees are present (Figure 5). The hot spot analysis showed that most of the trees found available during the winter were not significantly clustered. In the spring, there were a total of 3,334 trees identified as being seasonally available in early spring (7%), and a total of 8,887 trees available in late spring (18%), which is a large increase in abundance. Due to this increase, there are more significant clusters identified in the late spring hotspot analysis compared to the early spring analysis (Figure 6). For the summer, results showed that early summer had more trees accessible, with a total of 14,117 ready to be seasonally harvested (28%). Late summer had a total of 10,929 trees available for use (22%). The hotspot analysis for each breakdown of the summer season was similar, but early summer has a larger spread of significant clusters of edible trees compared to late summer (Figure 7). Overall, fall had the most trees with an EQR of "≥ 3" available for seasonal harvest. Early fall had a total of 33,115 trees identified with harvestable materials (67%), and late fall had a total of 30,356 trees identified (61%) (Figure 8). Similar to the summer hotspot analysis, many of the taxa in the fall covered multiple seasons, so the hotspot maps both have a very similar pattern of significant clusters and significant spatially distant areas. The clusters in early fall tend to be a few blocks larger compared to late fall.

Table 7. Seasonality Analysis of Baltimore Street Tree Taxa with EQR ≥ 3.

SEASON	NUMBER OF TREES IN SEASON	PERCENTAGE OF TOTAL EQR ≥ 3	NUMBER OF SPECIES IN SEASON	PERCENTAGE TOTAL SPECIES EQR ≥ 3
Early Winter	1,101	2%	5	6%
Late Winter	0	0%	0	0%
Early Spring	3,334	7%	8	9%
Late Spring	8,887	18%	17	19%
Early Summer	14,117	28%	25	28%
Late Summer	10,929	22%	23	26%
Early Fall	33,115	67%	48	53%
Late Fall	30,356	61%	37	41%

Following the methodology that I had completed for the overall analysis, I compared the HFPA dataset to each of the hotspots made for the seasons (Figure 9). Visually, there is more overlap with HFPA in summer and fall compared to the spring and winter. The fall shows to be the most accessible season, mirroring the hot spot analysis of all highly rated trees. The other seasons have hot spots that were not previously significant in the original analysis, leading to some seasons where accessibility is greater in some HFPA compared to others.

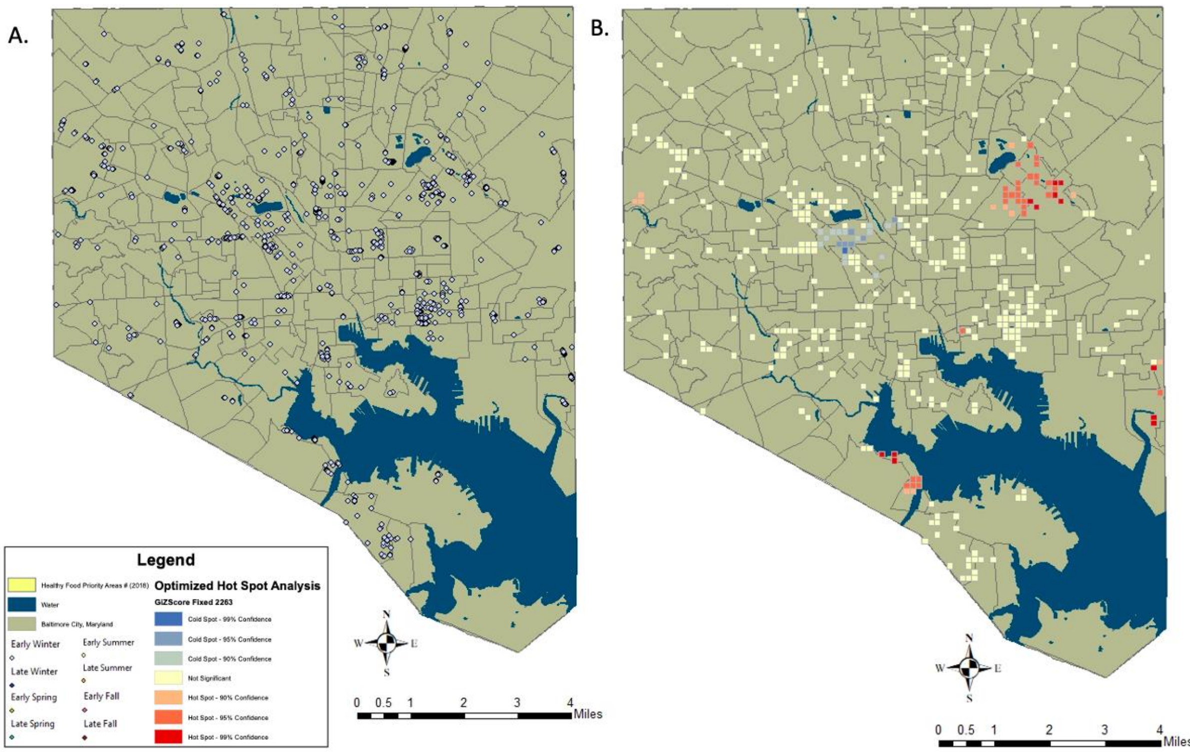


Figure 5. Seasonality Analysis of Taxa with EQR ≥ 3 in Winter. (A) Early Winter Taxa. (B) Hot spot analysis of taxa.

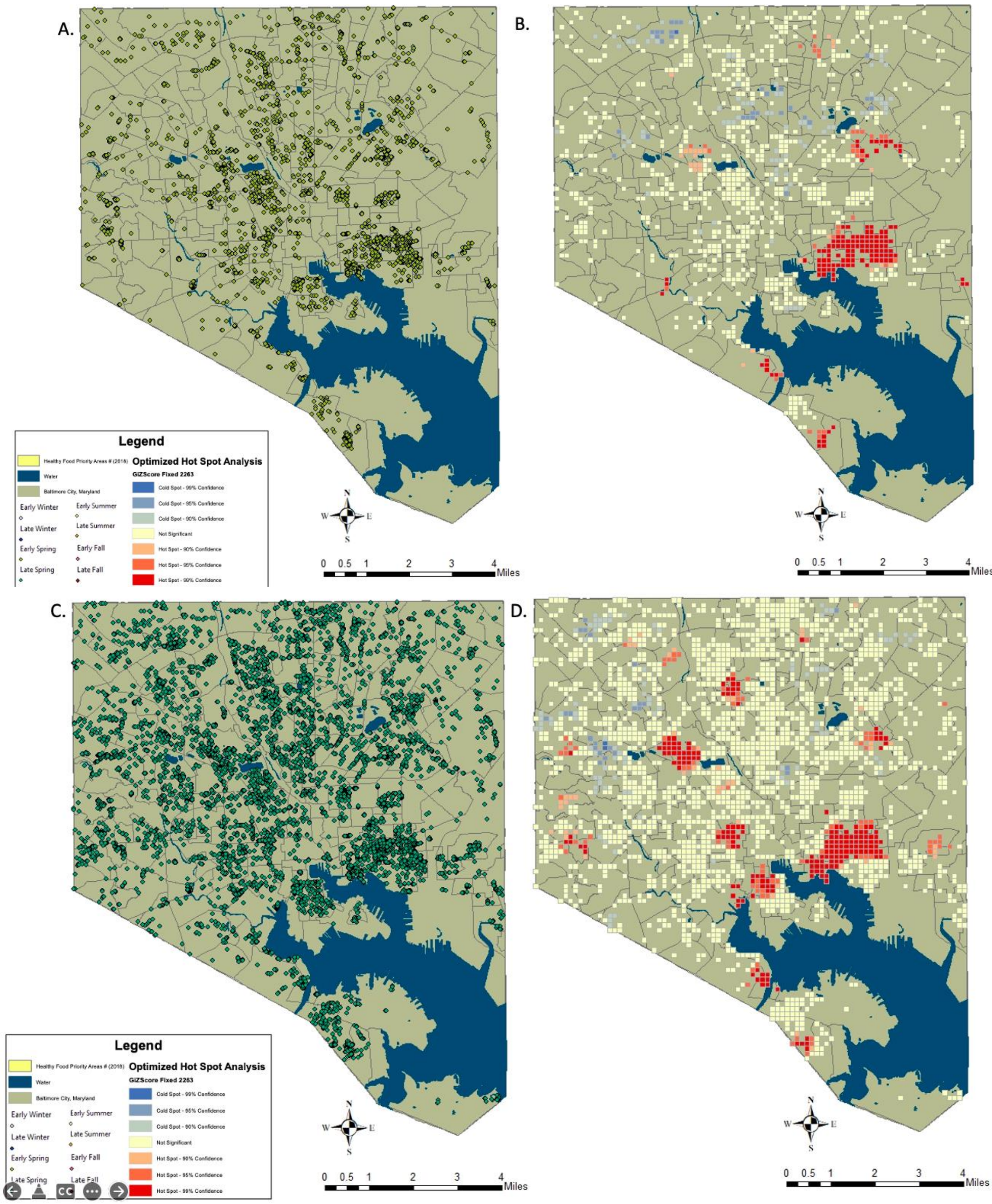


Figure 6. Seasonality Analysis of Taxa with EQR ≥ 3 in Spring. (A) Early Spring Taxa. (B) Hot spot analysis of taxa. (C) Late Spring Taxa (D) Hot spot analysis of taxa.

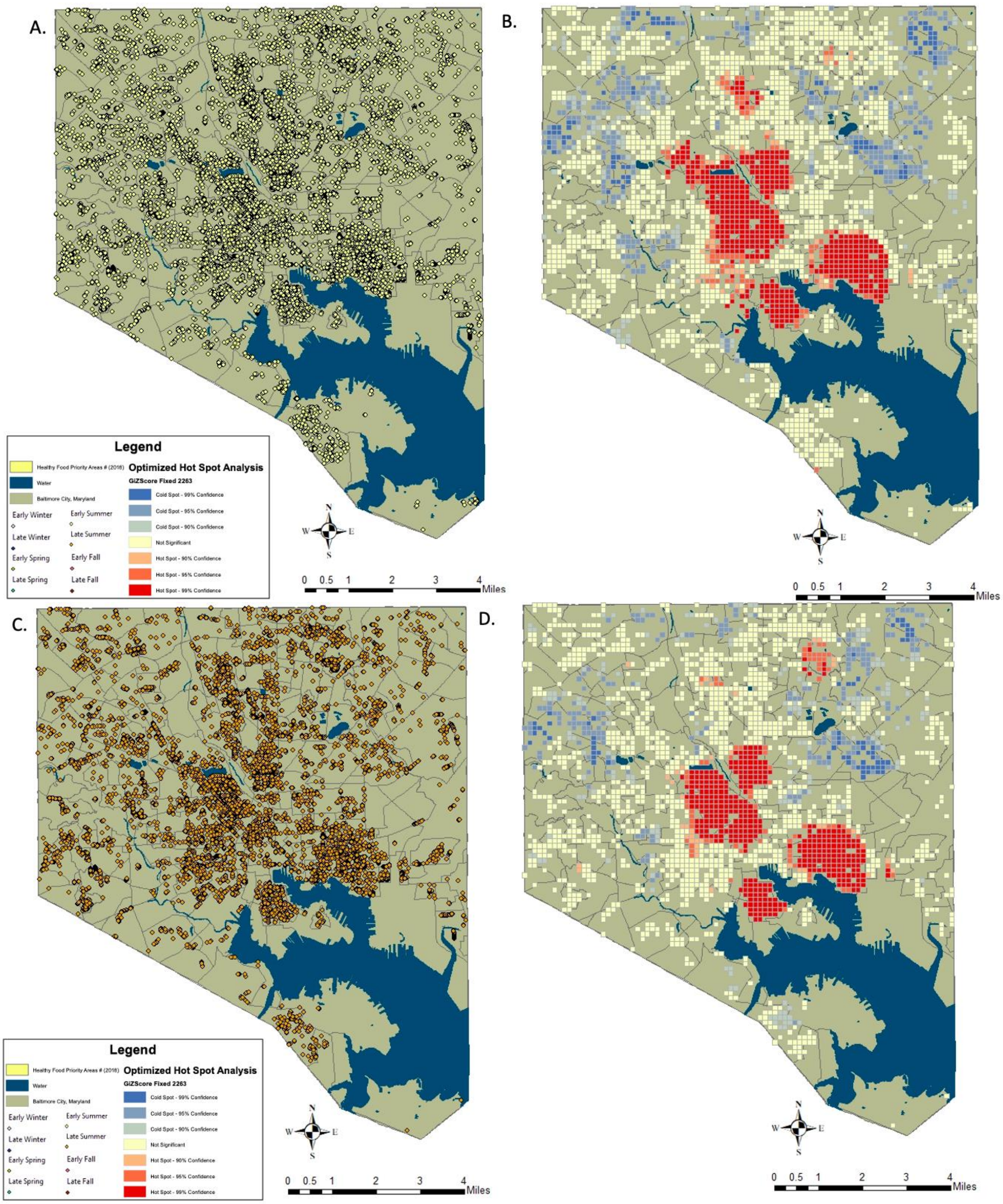


Figure 7. Seasonality Analysis of Taxa with EQR ≥ 3 in Summer. (A) Early Summer Taxa. (B) Hot spot analysis of taxa. (C) Late Summer Taxa (D) Hot spot analysis of taxa.

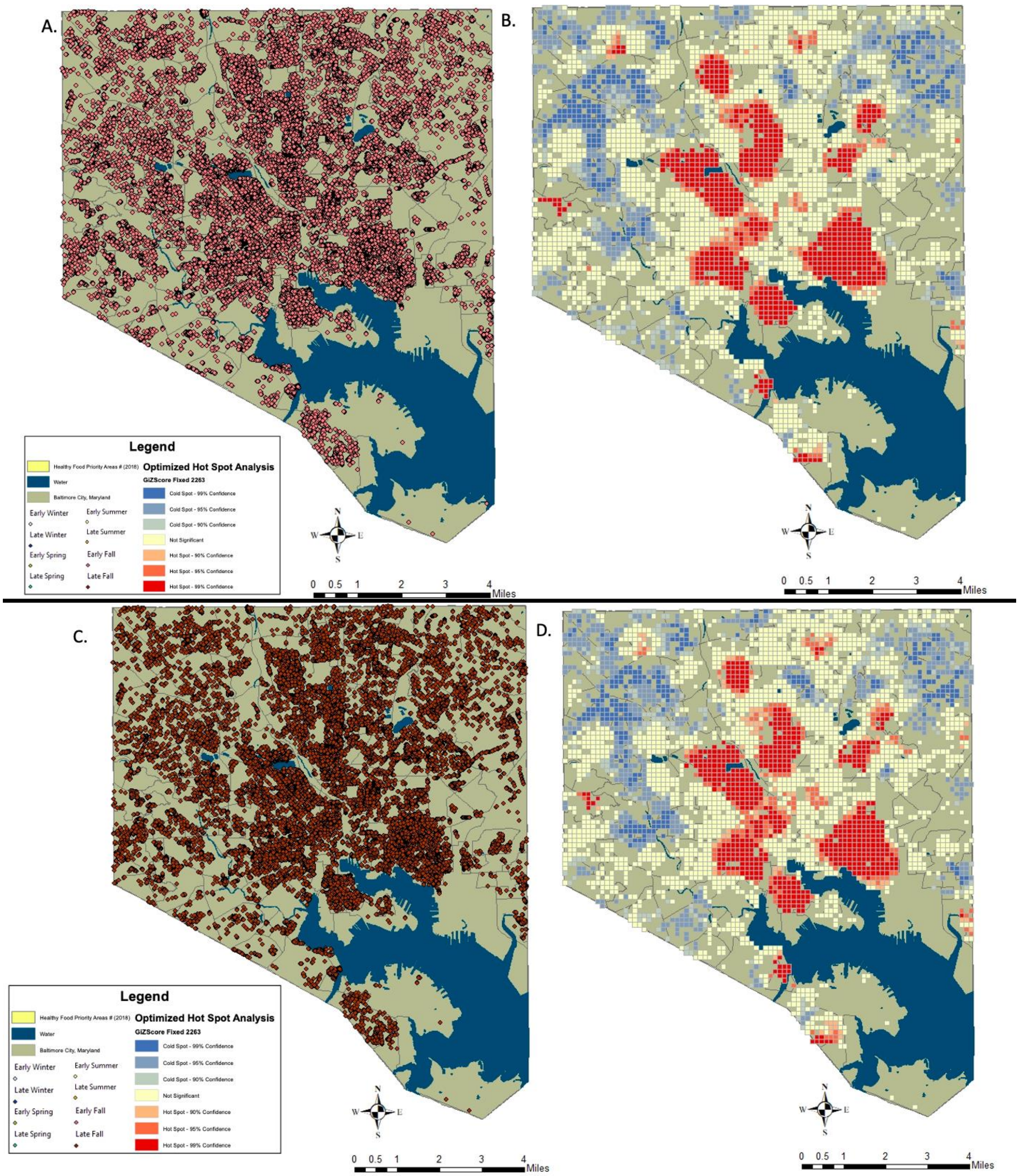
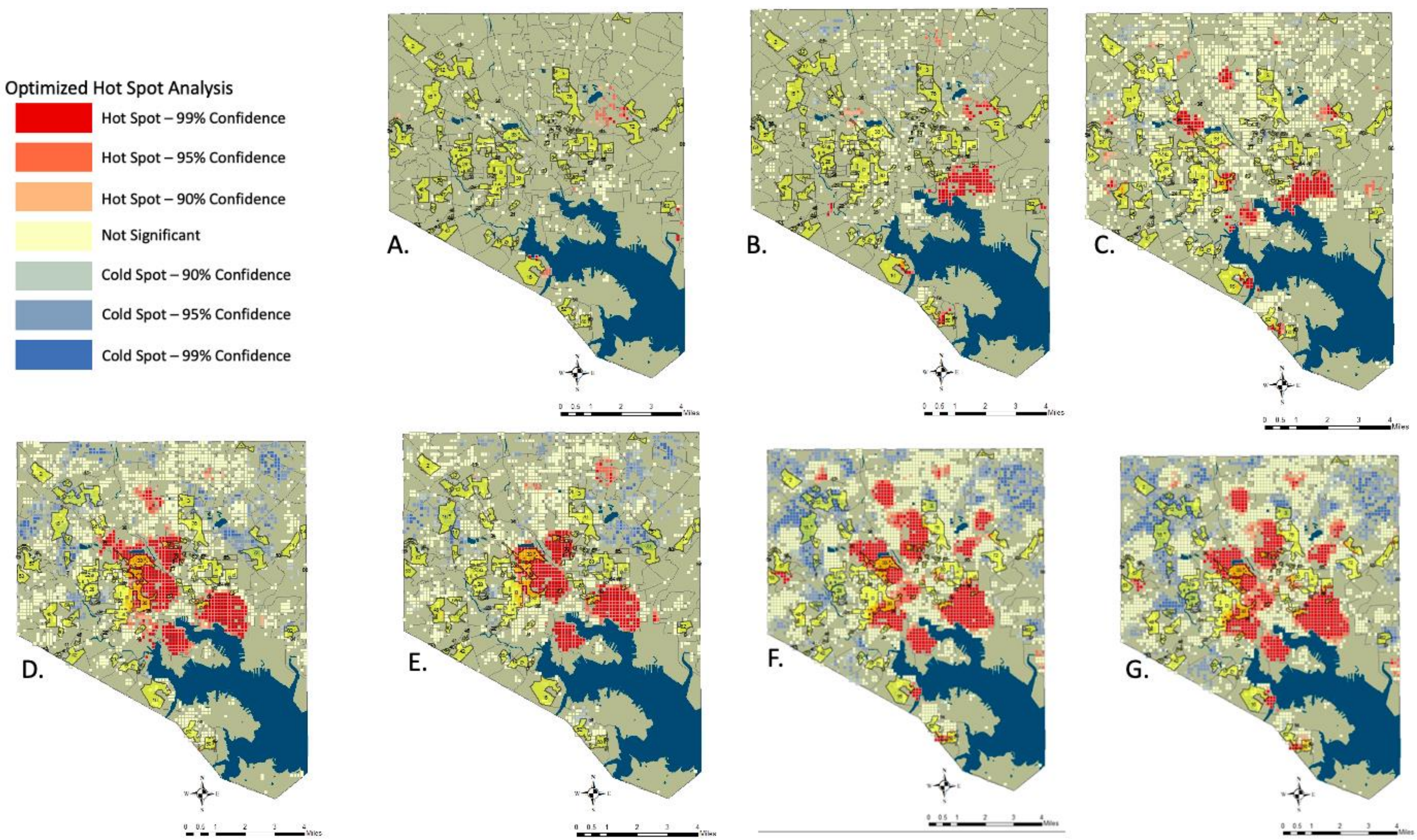


Figure 8. Seasonality Analysis of Taxa with EQR ≥ 3 in Fall. (A) Early Fall Taxa. (B) Hot spot analysis of taxa. (C) Late Fall Taxa (D) Hot spot analysis of taxa.



Optimized Hot Spot Analysis
Hot Spot – 99% Confidence
Hot Spot – 95% Confidence
Hot Spot – 90% Confidence
Not Significant
Cold Spot – 90% Confidence
Cold Spot – 95% Confidence
Cold Spot – 99% Confidence
A.
B.
C.
D.
E.
F.
G.

Figure 9. Seasonality Overlap Analysis of Taxa with EQR ≥ 3 with HFPA. (A) Map of Winter (B) Map of Early Spring. (C) Map of Late Spring (D) Map of Early Summer. (E) Map of Late Summer. (F) Map of Early Fall (G) Map of Late Fall.

DISCUSSION

The analysis suggests that street trees in Baltimore have the potential to provide access to highly rated food materials for residents. Analysis of the street tree inventory suggests that out of the 121,444 trees recorded, almost half (40.77%) are considered highly rated trees (those with an edible quality rating of three or higher), meaning that nearly every other tree in city is from a taxon that features a desirable edible material. Out of the three ratings making up the highly rated category, taxa with an EQR of three showed to be the most abundant, which includes the most abundant tree in the inventory, *Acer rubrum.* While taxa appear abundant in preliminary analysis, comprising of 340 total taxa in the city, 59 percent of these taxa have 30 or less individual trees attributed to them.

Distribution of these taxa throughout the city and spatial analysis of highly rated taxa suggest that there are some areas with greater access to higher rated taxa compared to others. Access is quantified by the overlap analysis of the hot spots of taxa that are rated three or higher for edible quality with the 84 HFPA categorized in the city. This approach provides a method of spatial analysis that can be used to better understand the availability of edible materials for communities that may lack access to food based on significant clusters of highly rated taxa. In our analysis, 25 percent of the 84 HFPA had at least a 50 percent overlap with hot spots of highly rated taxa, indicating access to edible materials. When considering individual tree presence in HFPA hot spots, some areas have substantial access to highly rated trees. With only a 70 percent overlap with hot spots, HFPA 30 has a total of 968 highly rated trees present, and HFPA 33 has 100 percent overlap with a hot spot, having 802 highly rated trees present. These HFPA contrast others that may visually have 100 percent overlap with a hot spot, but due to factors such as the size of the HFPA or the hot spot being created based on the proximity it has to other hot spots, no highly rated trees are present.

Presence of each individual highly rated taxa was also documented in each HFPA hot spot overlap. Four of the eight taxa with an EQR of 5 were present in HFPA, including *Tilia cordata*, the fourth most abundant taxa in the street tree inventory. These taxa may be of likely interest to forgers, even if they not to everyday residents, pointing to a bridge between existing practice and potential future harvests of these materials for distribution to people living in communities with food insecurity. Indeed, visual comparison of the highly rated taxa hot spots in Baltimore identified in our analysis with sites provided by foragers in a survey in 2017 (Synk et al 2017) show a clear correspondence. This may indicate that harvests of materials from these highly rated species already may occur in these areas.

The PFAF database also records the range of edible materials (fruit, leaves, blossoms, seeds, and flowers) provided by each highly rated taxa, with some producing up to three components. These results underrepresent the range of food materials that some of these taxa provide due to the consideration of not including edible components like oil, sap, inner bark, and manna, in the analysis due to the difficulty of obtaining the materials, or improper removal may result in damage to the tree (Hurley and Emery 2018). Over time, the interacting ecological and social factors that define the idea of foraging sustainability change due to demand, habitat sensitivity, and different foraging strategies that emerge through time (Hurley and Emery 2018). These changes raise concern about the impacts of harvests on the health of less abundant highly rated taxa in the city (Fischer and Kowarik 2020, Schunko et al 2021). Since urban street trees are rarely managed with food production in mind, the yield of edible materials provided by these taxa also needs to be considered when determining conditions of access (Bunge et al 2019).

Yet the lack of widespread information about the nutritional composition of harvested materials (i.e. edible quality ratings were used as a proxy for edible benefit) from these taxa suggests that future analysis on specific nutritional components of street tree yields would provide a clearer understanding of the specific nutrients urban residents can acquire from these food sources. This analysis would be especially helpful to thinking about mismatches with access to nutrient-dense foods in areas of food insecurity (Mollee et al 2017). This leads to conservancy in our results when considering taxa diversity and abundance in the city inventory.

Studies suggest that the collection of food materials derived from plants tend to have seasonal peaks around harvest seasons (Mollee et al 2017), which may indicate some foods are more accessible during a particular season compared to others. This analysis considered the availability of highly rated taxa in the inventory based on seasonality of these edible materials. Based on abundance, seasonal distribution suggests that fall is the season during which Baltimore residents have the greatest accessible to harvest edible materials from street trees, with 67 percent of the trees having edible materials accessible during that time. These findings suggest that PFAF and other databases can be used to analyze seasonal availability of highly rated taxa in Baltimore, access to specific food materials can be deeper understood based on availability of harvest.

To obtain the benefits from Baltimore's street trees documented through this analysis, residents need to have an ability to harvest and interact with these greenspaces. By analyzing the distribution, seasonality, and harvestable materials of the taxa in the city in relation to HFPA, managers receive greater information about the decisions their urban forest and land management decisions may have on access to these species and their edible materials. These decisions can include changes to rules and policy that govern the legality of harvests, contributing towards maintaining access of these taxa for edible use, increasing the diversity of taxa with highly rated edible materials, and managing existing useful taxa based on the edible materials they provide. Existing research on urban forests and foraging suggests that managers and their decisions influence who uses them, how species are managed, and what benefits residents can obtain from these ecosystems (McLain et al 2012). This may control decisions relating to species composition, interactions with public nature, and management of certain trees for aesthetic instead of material gain (Charnley et al 2016).

CONCLUSION

Baltimore's street trees feature a range of edible materials that may be of interest to residents who may lack access to healthy and nutritious foods. A portion of the tree taxa found in the city feature edible materials that are highly rated for edible quality. In terms of access to these materials, our analysis identifies hot spots, or clusters of tree taxa with highly rated edible materials, to understand how the distribution of these materials overlap with food insecure areas across the city. The overlap analysis demonstrated that these hot spots tend to cluster in the center of the city, and that some HFPA have greater access than others due to the distribution of highly rated trees. Further analysis of seasonality suggests that the window during which some food materials from highly rated taxa can be accessed is limited based on their seasonal availability. Taken together, these findings reveal that there are only certain special and temporal instances where there is substantial availability of foods from highly rated species that to food insecure communities. Still, we are reminded that, given our focus on hot spots, these estimates are conservative.

By mapping street tree taxa and understanding when highly rated edible materials are harvestable from these trees, both based on seasonality and the taxa, planting initiatives may provide additional information for managers to organize harvests that provide residents with accessible food materials year-round. This analysis may also inform managers decision making when developing and enforcing rules and terms of access to these taxa for urban residents, including improving access by relieving regulatory barriers and improving education initiatives about which taxa in the inventory are useful for food. Since our analysis only considers street trees in the city, and not other forested greenspaces or elements of the urban forest, further analysis is needed to more fully understand the ways tree (and other plant) taxa are distributed in these spaces. This further analysis can create a better understanding of how access to edible materials in Baltimore's urban forest could enhance efforts to reduce food insecurity in the city.

In the absence of a comprehensive nutritional database with detailed information about typical woody species and their edible materials, we suggest that using the PFAF to analyze edible street tree taxa in the city provides one way to consider questions about urban forests and food insecurity. One advantage here is the extensive coverage of herbaceous and woody plant species across multiple biome that can facilitate analyses in cities that have a street tree inventory and spatial information on food insecurity in their city. Further analysis of these taxa, which include nutritional components and yield of edible materials as well as possible considerations of tree health, sex, age, the range to other pollinators also would enhance our understandings about access to nutritious and healthful food materials.

Our findings suggest that harvests of highly rated edible materials are available in areas of the city that experience food insecurity, thereby providing potential access for residents in these areas. Further research is needed to determine whether and how Baltimore's residents might think about or access these edible materials as part of reducing food insecurity. The opinions of and behaviors by people who live in these areas should not be assumed in any efforts to move towards utilizing street trees for food provision. However, community can be built through organizing and distribution of edible materials, and as stated before, other studies in Baltimore suggest that use of these edible materials may already occur in the city. Conclusively, street trees provide a range of harvesting opportunities, in terms of taxa, edible materials, and seasonal availability, that can address food insecurity in Baltimore, Maryland.

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