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Assessment of Howard County, Maryland's Tree Canopy and Forest Cover

April 2022

Tree Canopy and Forest Cover

Tree canopy (TC) commonly refers to the leaves, branches, and stems that cover the ground when viewed from above. Tree canopies provide many benefits including reducing high temperatures, improving water quality, reducing air pollution, providing wildlife habitat, saving energy, increasing property values, offering social and educational amenities, and providing aesthetic benefits. These benefits are predominately associated with forests, but with many broad summaries of canopy cover from coarse satellite images, there has been a progressive conflation of these terms in remote sensing. Because rural landscapes typically contain larger areas of tree canopy with a high degree of contrast from agricultural land uses, it is not always necessary to map trees with a precise level of spatial resolution. However, in suburban and urban landscapes, much tree canopy is interspersed with other land uses, making high resolution mapping essential for understanding canopy distribution. Thus, urban tree canopy (UTC) mapping has led to an improved appreciation of the details of canopy characteristics and has highlighted an increasing need to distinguish tree canopy from forests.

One of the common misconceptions that has accompanied increases in spatial resolution from rural to urban landscapes is that the woodland features being mapped have similar properties, but this is often not true. With image resolution approaching 1 meter or finer, it is possible to map and distinguish individual tree crowns, just as large expanses of canopy were once mapped in rural landscapes. However, forests involve much more than just a group of trees, and they confer many additional benefits that trees alone do not. Forests are reproducing and self-sustaining assemblages of trees, plants, insects, microbes, and animals, that store and accumulate water-absorbing organic matter in the ground and cycle several key macronutrients. Therefore, it is important to 'distinguish the forest from the trees' when using UTC maps. Howard County defines minimum canopy dimensions for "forest" in the County Forest Conservation Act as canopy with a minimum area of 10,000 ft^2 and a minimum width of 35 ft. Arguably, this definition has more in common with a stand or a grove of trees, and it is recommended that this definition be assessed and revisited relative to the county's sustainability objectives. A suitable definition for forest will vary based on local natural systems. For example, the United Nations Food and Agriculture Organization uses a definition of 0.5 hectares (1.2 acres) of wooded land greater than 5 meters in height with at least 10 percent canopy cover. As a global organization, the United Nations definition naturally includes semi-arid and arid climates. In a humid temperate climate such as Maryland, it seems reasonable to expect something closer to a closed canopy (e.g., >75% cover) over 0.5 hectares with some criteria to characterize woodland interior from edge.

Project Background and Objectives

This document reports on an assessment of tree canopy and forest cover within Howard County, Maryland using imagery originally collected in 2013 and 2018. To perform the comparisons in this report, we made use of a harmonized land cover change product produced by a collaboration between the University of Vermont and the Chesapeake Conservancy. This project is a collaboration between the County's Office of Community Sustainability and the University of Maryland Baltimore County (UMBC) and serves as an update to a previous report that used 2007 imagery. At the time of this report, the updated landcover classification based on 2018 imagery had just been completed for Howard County.

The goals of this project were (1) to develop an estimate of overall tree canopy and forest cover across the county, (2) to summarize the distribution of tree canopy and forest cover across all parcels within the county, as well as according to property land use designations, (3) to develop a "negative layer" indicating locations where future planting might enhance the County's Green Infrastructure Network (GIN), and (4) to assess whether the shape of large woodland "hubs" within the GIN affects the composition and structure of overstory stems.

Howard County also received electronic copies of the data analyzed and layers created through this investigation for use with their existing interactive maps. In order that this project may serve as a baseline for additional assessments, detailed methods are provided in an accompanying appendix to enable future replication.

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How Much Tree Canopy and Forest Cover Does the County Have?

Howard County covers nearly 253 mi^2 or just over 162,045 acres in a triangular portion of central Maryland. Its northern and southwestern borders are defined by the river valleys of the Patapsco and Patuxent rivers, respectively, as they drain from the Mid-Atlantic Piedmont to the Coastal Plain. Its eastern border rests on the physiographic boundary between the Piedmont and the Coastal Plain, located midway between the I-95 and I-295 corridors. Land cover data was collected from aerial imagery of the County in 2013 (Figure 1).

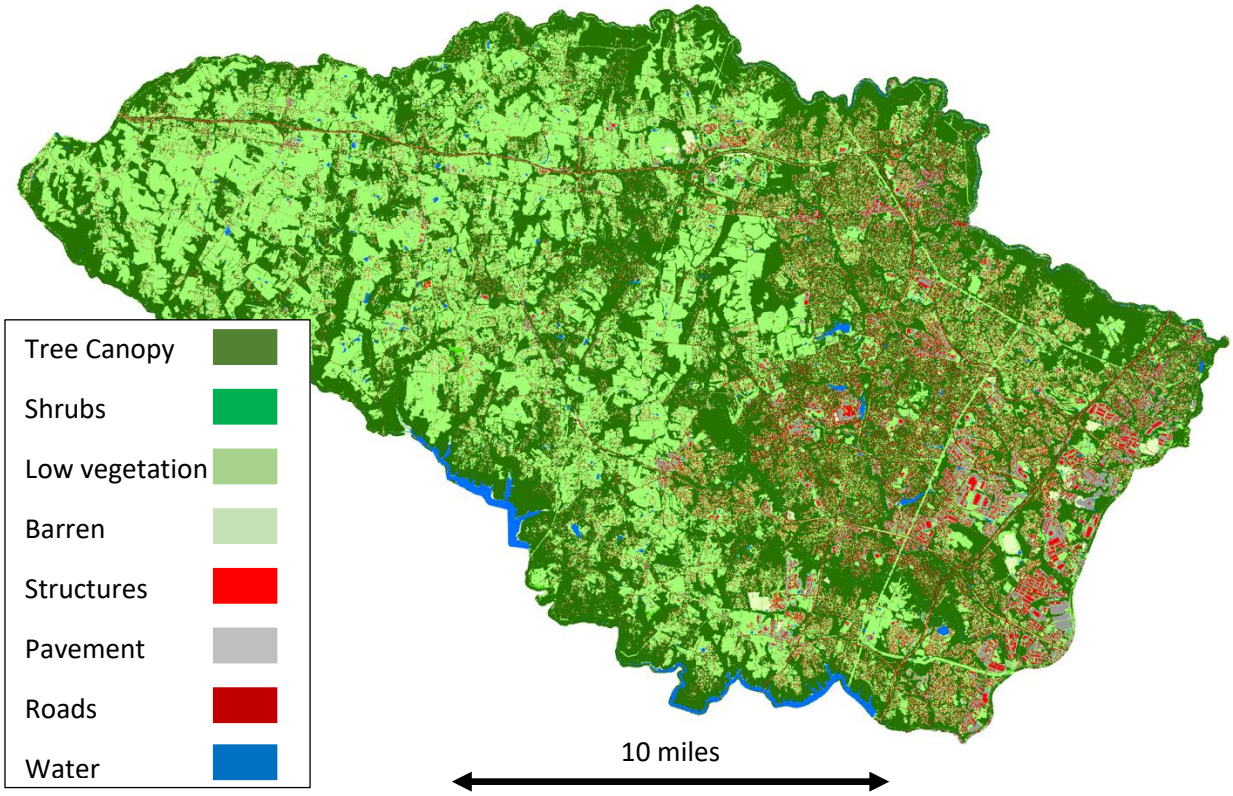

Figure 1. High-resolution land cover for Howard County, Maryland from 2013 imagery.

The 2013 and 2018 imagery was classified into the cover types shown in Table 1, then grouped for further assessment.

Table 1. Landcover classes developed from 2013 and 2018 aerial imagery for Howard County

LandC	Water	Soft Surfaces/Vegetation				Hard Surfaces			Covered Surfaces		
Class	water	trees	scrub	grass	barren	structures	impervious	roads	can_struct	can_imp	can_roads
Group	notsuit	existTC	possTC	possTC	possTC	notsuit	possImp	notsuit	notsuit	possImp	notsuit

For the purposes of this analysis, *Total Tree Canopy*, or what can be seen from above, was defined as the sum of the tree class, as well as canopy over structures, roads, and other

impervious cover. This agglomerated class is what was summarized as part of the landcover assessment in 2007. In more recent land cover classifications, canopy covering and/or obscuring hard surfaces or *Hard Canopy*, has been distinguished separately for a more accurate summary. Canopy over unpaved surfaces, or *Soft Canopy*, represents a more accurate interpretation of existing tree canopy (existTC) than Total Tree Canopy for many applications such as quantifying ecosystem services typically associated with forests or identifying areas suitable for future planting. In this case, Total Tree Canopy was dominated by Soft Canopy not over hard surfaces like buildings or pavement. Some landcover classes are in the process of regrowth (Shrubs) or can be planted and converted to tree canopy (Low vegetation and Barren) and were grouped as possible tree canopy (possTC). Other landcover classes have been hardened but may nonetheless be converted to tree canopy with greater effort (both impervious surfaces and tree canopy over impervious), and these were interpreted as possible impervious tree canopy (possImp). Finally, roads and structures, whether covered or not, as well as water bodies, were deemed unsuitable (notSuit) for future planting.

In 2013, 49.6% (80,305 acres) of County land area was covered by Total Tree Canopy (TTC; or hard canopy plus soft canopy), down from 50% (80,953 acres) in 2007. The acreages in 2007 and 2013 may not be directly comparable due to approximation in the 2007 report and improvements in image classification methods. However, a more detailed investigation is beyond the scope of this effort. In any case, the 2018 TTC had dropped slightly to 49.1% (79,495 acres) of county land. However, in both 2013 and 2018 it was possible to separate hard and soft canopy, so *existTC* was really **47.7%** (**77,229 acres**) in 2013 and **47.2%** (**76,420 acres**) in 2018 (Figure 2). The amount of land that could potentially be planted, defined here to include low lying vegetation (*possTC*) as well as some impervious surfaces (*possImp*), increased from 43% in 2007 to **43.2% (69,943 acres)** in 2013 (36.9% *possTC* + 6.3% *possImp*), driven by both canopy loss and impervious expansion. This slight trend continued in 2018, with **43.4%** (**70,267 acres**) falling into this category (36.7% *possTC* + 6.7% *possImp*). Meanwhile, the amount of land not suitable for planting, defined as water, buildings, roads, and canopy over those surfaces, increased from ~7.0% in 2007 to **9.0% (14,571 acres)** in 2013 and **9.3%** (**15,057 acres**) of County lands in 2018.

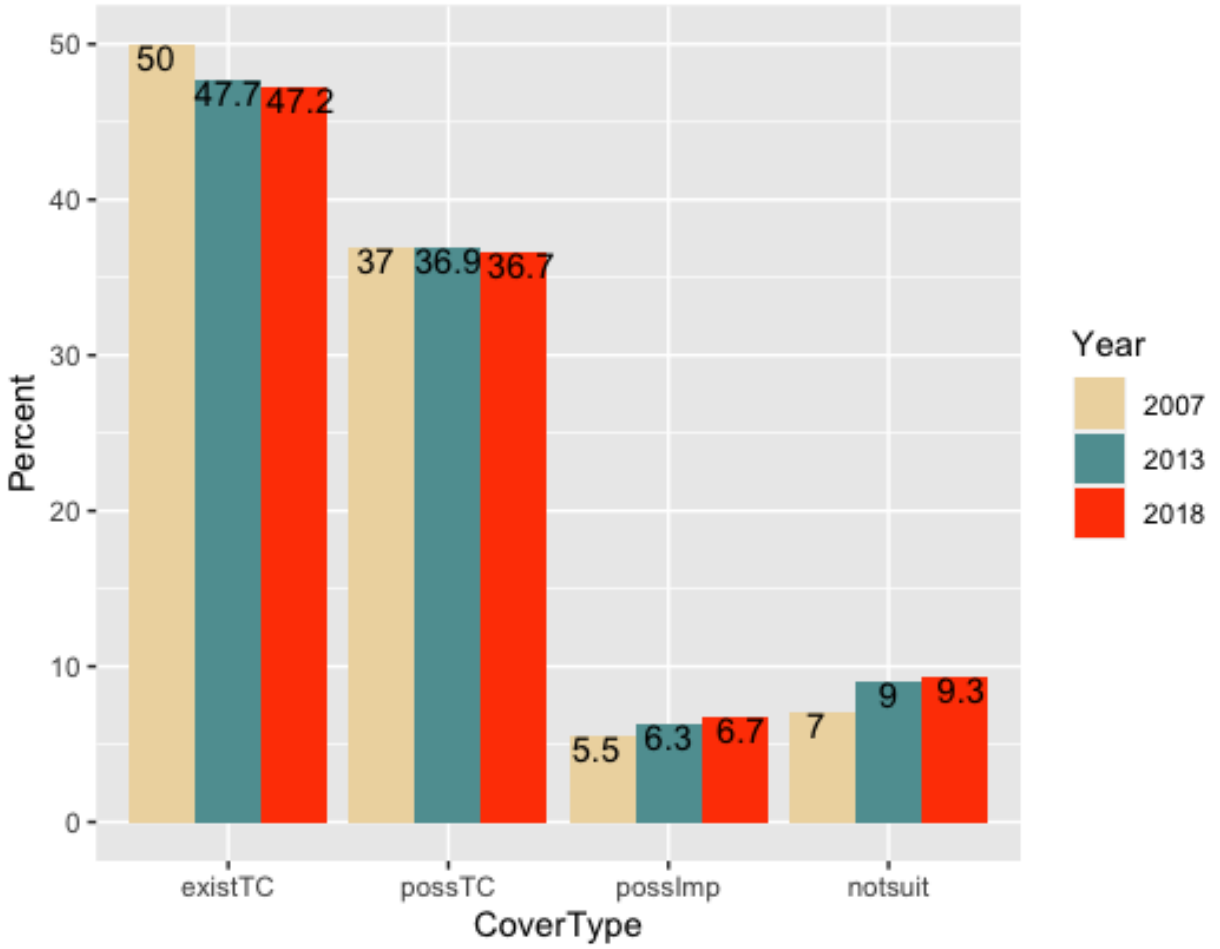

Figure 2. Comparison of land cover groups in Howard County, Maryland in 2007, 2013, and 2018. Existing tree canopy decreased but part of the difference shown between 2007 and 2013 was due to a change in definition of *existTC* from Total Tree Canopy (TTC) to *Soft* Canopy (canopy over pervious surfaces). TTC dropped from 50% in 2007 to 49.6% in 2013 and 49.1% in 2018. Canopy losses were not converted to land with potential for regrowth (*possTC*), which also declined, but instead in impervious surface expansion or the addition of roads and buildings (this was true after 2013 even though some increases between 2007 and 2013 were likely due to distinguishing *Hard* Canopy over roads, buildings, and impervious cover).

Overall, Howard County's existing tree canopy contracted between 2007 and 2013. Some of this difference was due to the inclusion of Hard Canopy (canopy over impervious surfaces, roads, or buildings) that was not distinguished from Soft Canopy in 2007. However, since these totals amounted to ~2% of the total canopy cover in 2013 and 2018, it seems reasonable to expect a similar pattern occurred in 2007. Regardless, canopy loss continued in 2018. In both temporal increments, land clearing for development accounted for most canopy losses.

Forest Cover

Forest cover, as defined by Howard County, was a subset of extant Soft Canopy, which was itself a subset of Total Tree Canopy. As expected, the distribution of 2013 and 2018 Forest cover was consistent with larger patches of Soft Canopy, being primarily associated with parkland on the county's northern and southern borders, along with open space, parkland and easements on some internal river networks (Figure 3).

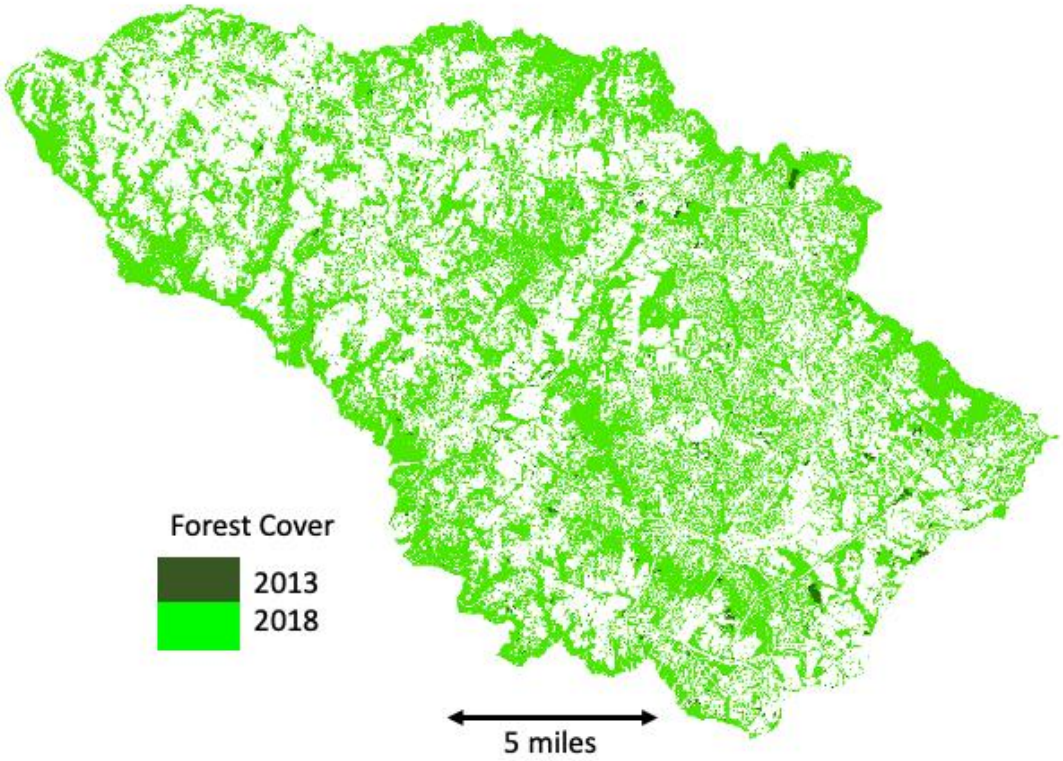

Figure 3. Forest cover in Howard County, Maryland derived from 2013 and 2018 aerial imagery and lidar data. High-resolution (3.28 ft) imagery was used to develop land cover rasters, then contiguous tree canopy not over hard surfaces was used to identify individual patches >10,000 ft^2 and wider than 35 ft. In this map, 2018 cover is overlain on 2013 cover to highlight areas of forest clearing.

In 2013, forest cover occupied **45.2% (73,181 acres)** of the County as **176,761 patches** for an average patch size of 0.41 acres. In 2018, forest cover declined to **44.6%** (**72,210 acres**) over 191,256 patches for an average patch size of 0.38 acres. Because forest cover was not quantified in 2007, we do not know how these patterns changed in previous years (Figure 4). However, a report on 2013 and 2018 data should serve as a baseline for future assessments. For example, during the production of this report, it was observed that several large areas of Forest cover visible at the county extent had been subsequently cleared (Figure 3). Also, an

increase in the number of forest patches along with the smaller average patch size were indicators of increased fragmentation.

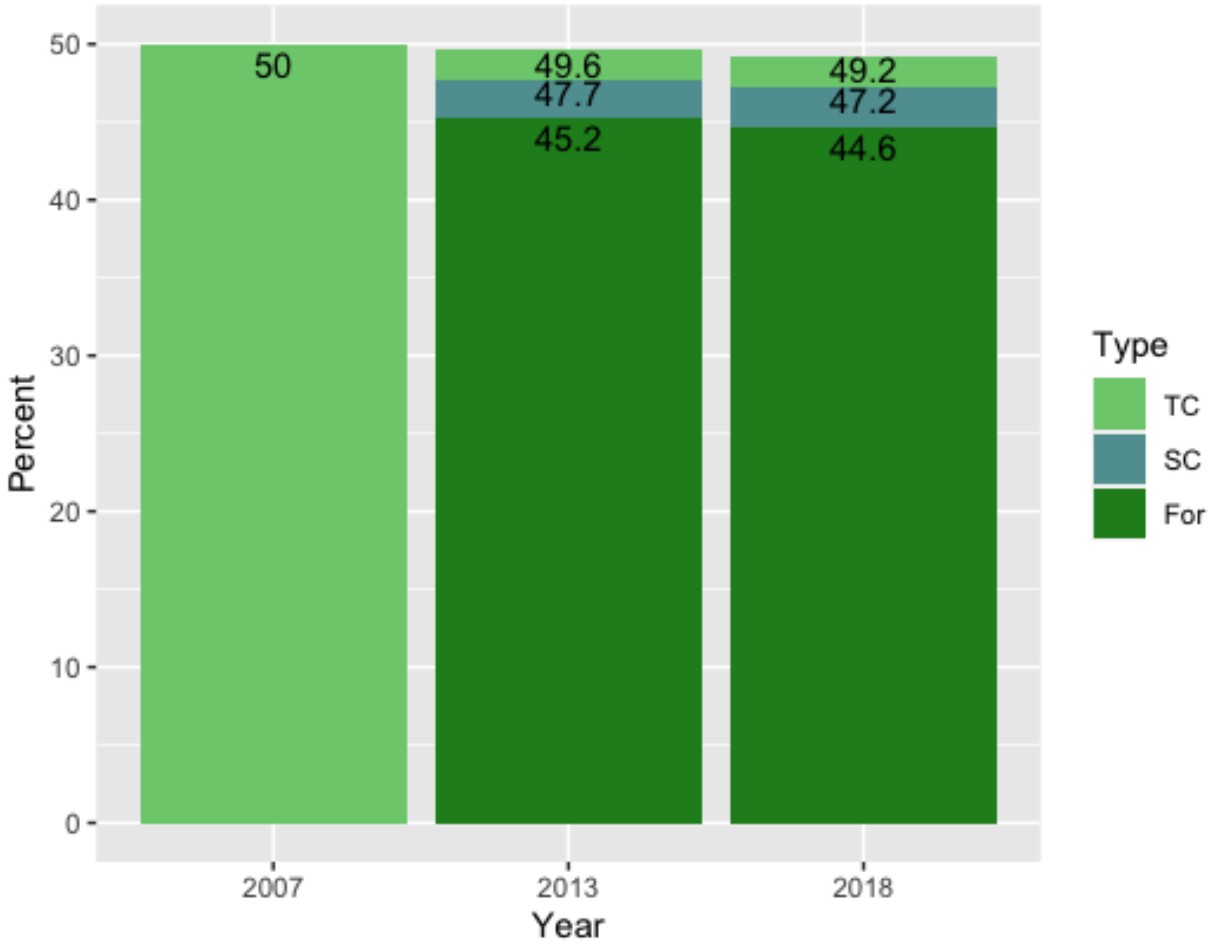

Figure 4. Comparison of Total Tree Canopy (TTC) percentages in Howard County, Maryland from 2007, 2013, and 2018. In 2013 and 2018, TTC cover was disaggregated into Soft Canopy (SC), and further distinguished as Forest cover (For). Between 2013 and 2018, existing TTC decreased more slowly than SC and For, an indication that clearing disproportionately affected larger, more contiguous areas of tree canopy.

All else being equal, and in the absence of land development pressure, both tree canopy and forest cover should increase slightly through time as crowns grow. Thus, the average patch size should increase and the number of patches should remain static or decline as smaller stands close intervening canopy gaps. Because the opposite pattern prevailed, the overall conclusion was that loss of canopy and forest fragmentation continued concurrently with land development.

Parcel and Land Use Summary

Once land cover was summarized by each parcel within the county property layer, it was possible to assess the distribution of tree canopy cover as well as forest patches and their land use distribution. Designated land uses associated with Howard County's parcel layer were aggregated and simplified for ease of interpretation and used to summarize land cover (Figure 5, Table 2). Howard County's tree canopy remained associated with residential land uses (Res), accounting for over 23% of County lands, whereas exempt properties (Exmpt; largely owned by Howard County or State of Maryland, but also disabled veterans, houses of worship, and some hospitals) and agricultural land uses (Agr) account for the next 25%. These proportions declined slightly from 2013 to 2018. Commercial (Com) and industrial (Ind) land uses were relatively minor players, but their proportions of *existTC* also declined.

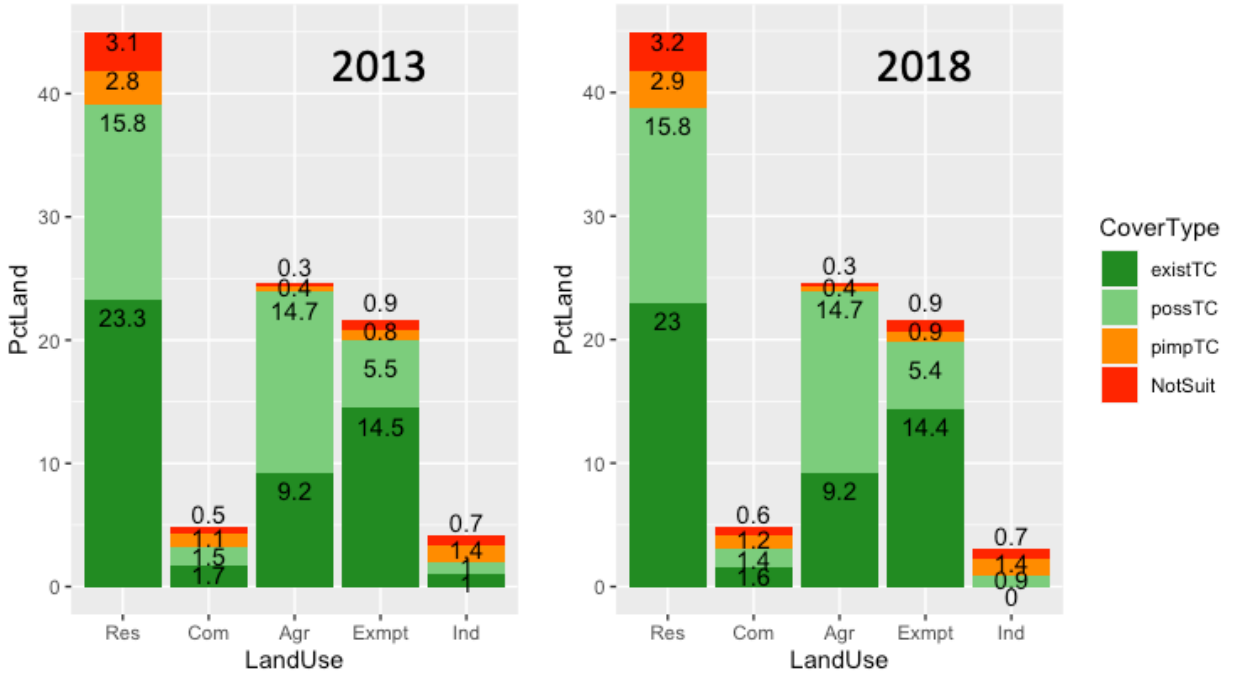

Figure 5. Comparison of cover type acreage across land use classes in Howard County, Maryland from 2013. Land uses consist of residential (Res), commercial (Com), agricultural (Agr), exempt (Exmpt), and industrial (Ind). Cover types consist of existing tree canopy, possible tree canopy, possible impervious tree canopy, and impervious surfaces not suitable for conversion. Numbers indicate the percentage of each cover type acreage relative to all land within Howard County.

Because residences accounted for nearly 45% (72,695 acres) of County lands, it was not surprising that it accounted for similar fractions of existing and possible tree canopy (i.e., PctCT; Table 2), as this represented a broad swath of county area. However, as a dominant land use residential properties also contained relatively high levels of impervious cover, as one might expect from commercial or industrial uses. As a fraction of their land use category (PctCAT; Table 2) exempt land use surpassed residential areas for their canopy proportion, which was

hardly surprising since many County and State parks were included in this class. Similarly, it made sense that agricultural uses over-represented areas available for tree planting and reforestation. These land use aggregations and land cover proportions have been added to the property data table for ease of integration with other County datasets (Figure 6).

Table 2. Tree canopy metrics summarized by land use and cover type designation*.

LandUse	CoverType	2013Acres	PctLand	PctCT	PctCat	2018Acres	PctLand	PctCT	PctCat
Agr	existTC	13,682	9.2	18.6	37.5	13,640	9.2	18.7	37.4
Agr	possTC	21,790	14.7	38.2	59.7	21,761	14.7	38.4	59.6
Agr	pimpTC	591	0.4	6.2	1.6	645	0.4	6.3	1.8
Agr	NotSuit	448	0.3	5.5	1.2	466	0.3	5.5	1.3
Com	existTC	2,488	1.7	3.4	34.7	2,393	1.6	3.3	33.3
Com	possTC	2,208	1.5	3.9	30.8	2,104	1.4	3.7	29.3
Com	pimpTC	1,688	1.1	17.6	23.5	1,842	1.2	18.0	25.7
Com	NotSuit	791	0.5	9.7	11.0	836	0.6	9.8	11.7
Exmpt	existTC	21,512	14.5	29.2	67.0	21,380	14.4	29.3	66.5
Exmpt	possTC	8,097	5.5	14.2	25.2	8,060	5.4	14.2	25.1
Exmpt	pimpTC	1,215	0.8	12.6	3.8	1,343	0.9	13.1	4.2
Exmpt	NotSuit	1,303	0.9	16.0	4.1	1,344	0.9	15.8	4.2
Ind	existTC	1,451	1.0	2.0	24.3	1,428	1.0	2.0	23.9
Ind	possTC	1,417	1.0	2.5	23.7	1,370	0.9	2.4	23.0
Ind	pimpTC	2,018	1.4	21.0	33.8	2,066	1.4	20.2	34.6
Ind	NotSuit	1,081	0.7	13.3	18.1	1,103	0.7	12.9	18.5
Res	existTC	34,567	23.3	46.9	51.9	34,146	23.0	46.8	51.2
Res	possTC	23,458	15.8	41.2	35.2	23,411	15.8	41.3	35.1
Res	pimpTC	4,099	2.8	42.7	6.2	4,328	2.9	42.3	6.5
Res	NotSuit	4,533	3.1	55.6	6.8	4,773	3.2	56.0	7.2

*PctLand refers to percentage of Howard County, PctCT refers to percentage of a particular cover type, whereas PctCat refers to percentage of a particular land use category.

Forest cover was similarly summarized across land use classes for contrast with existing tree canopy. According to the County definition, forest cover made up >90% of existing tree canopy in all land uses, yet residential and agricultural lands showed the greatest discrepancies (Figure 6).

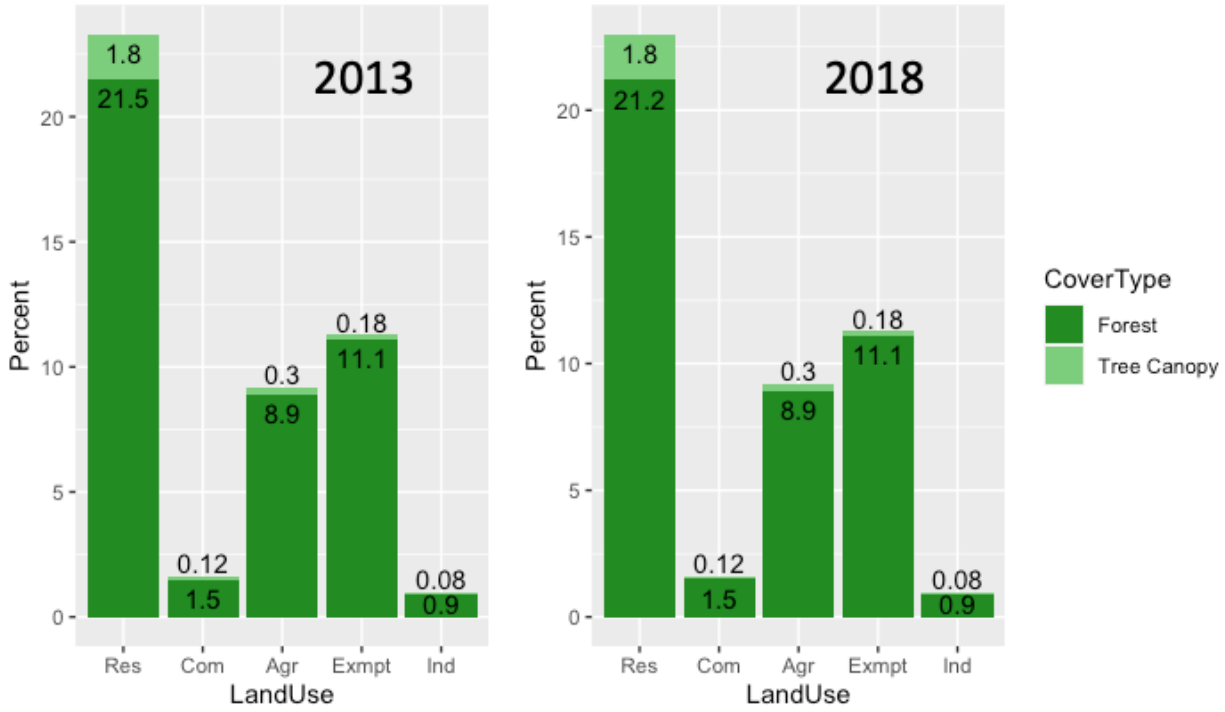

Figure 6. Comparison of tree canopy cover types from 2013 and 2018 across land use classes as a percentage of Howard County, Maryland. Land uses consist of residential (Res), commercial (Com), agricultural (Agr), exempt (Exmpt), and industrial (Ind). Cover types consist of existing tree canopy and forest defined as greater 10,000 ft^2 in area and more than 35 ft wide.

Residential land uses contained the greatest amount of forest cover but the lowest fraction relative to extant tree canopy (Figure 6). By contrast exempt land uses showed the second greatest percent forest cover but the largest forest proportion of tree canopy. Regardless, summary by parcel allows for detailed examination of the distribution of canopy and forest cover (Figure 7).

Figure 7. Comparison of parcel data layer: over aerial imagery (A), showing percent tree canopy (B), and percent forest cover (C) for several subdivisions in Howard County, Maryland. Although the distinctions between panel B and C may at first appear small, subdivisions on left appear in B to have distributed canopy when compared to the subdivision on the right, when in fact C shows very little forest cover as

opposed to tree canopy. Part of the subtlety in this comparison may be a result of the inclusive definition of the term 'forest' used by the County, which fails to exclude most canopies.

Green Infrastructure Network "Negative Layer"

As part of the County's sustainability planning, a Green Infrastructure Network (GIN) has been identified and delineated to maintain connectivity along "corridors" between "hubs," which contain larger areas of forests and wetlands. Our objective involved identifying parcels and the areas within parcels falling within the GIN that might reasonably be considered for future planting efforts. Our map started with hubs and corridors, which were used to select parcels and portions of parcels falling within the GIN. From these areas, we removed areas with tree canopy, building setbacks, utility right of ways, water bodies, 10 ft streamline buffers (because the stream itself cannot be planted) and stormwater management features. The result was an individual layer that may help guide future replanting efforts throughout the County as well as specifically in the GIN (Figure 8).

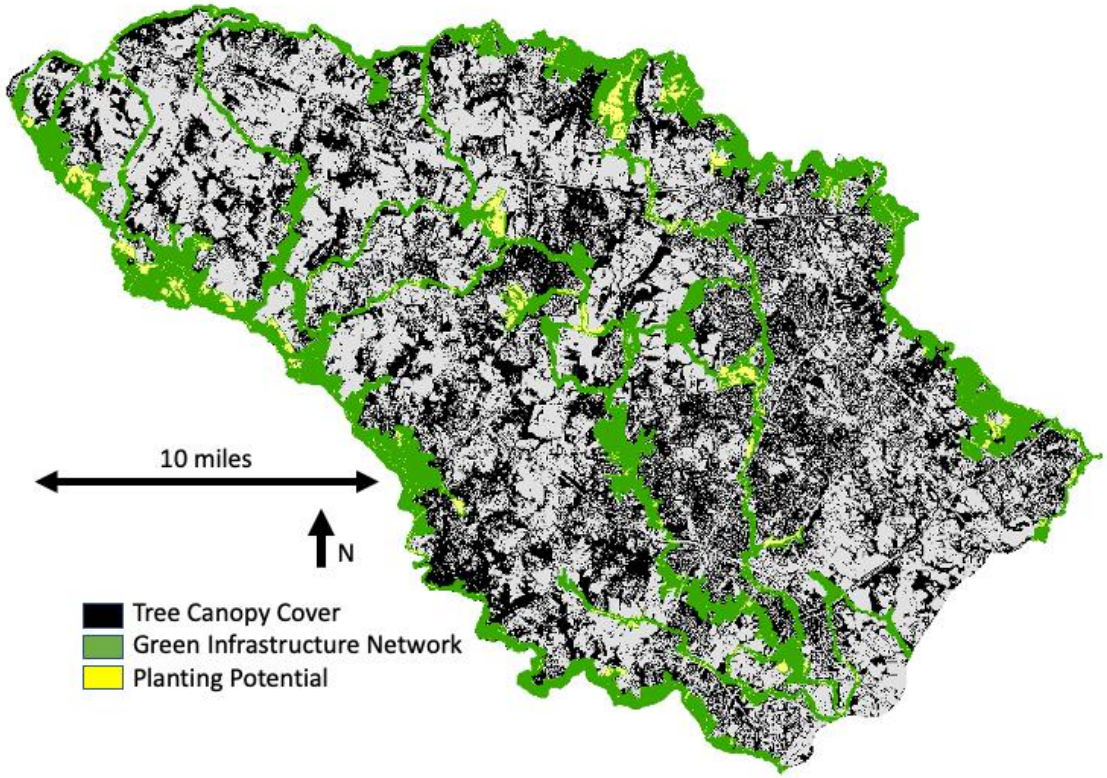

Figure 7. Map of canopy cover in Howard County, Maryland from 2018 showing the Green Infrastructure Network and areas with reforestation potential.

As expected, many of the areas identified for potential planting occurred within or along the margins of hubs where Forest cover is incomplete or inadequate. Many of the more sizeable of these locations fell along or within the state park boundaries along the County's perimeter. However, a few more occurred at hub locations within the County interior, and still more fell along the corridors in between hubs.

Closer inspection revealed some problems with the compatibility of layers supplied by the county and may result in errors or incomplete data analysis. Specifically, the GIN hub and corridor features did not respect county boundaries, and indeed several other maps seemed to have different ideas about where the county boundary fell. As a result, we clipped or masked products relative to the County polygon. Also, many coincident polygon boundaries did not quite agree, leaving sliver polygons following overlay analysis. We endeavored to remove these where possible, but some remain in the output. Finally, many data projections were nominally the same (i.e., NAD83 stateplane) but had different labels, which can produce incompatibility in different packages or software operations.

Hub composition and structure

To better understand the influence of hub shape on tree species composition and structure in County woodlands, nine hubs throughout the County were assessed during the summer of 2021. Selection of the hubs proceeded based on geographic dispersion across the county and relative accessibility given time and budgetary constraints. The primary question being addressed was whether edge effects could be documented across hubs, as these would have implications for limitations on the efficacy of complex GIN boundaries, particularly “arms” in the hub extent that might approach minimum width criteria. In general, less edge and larger areas were thought to protect the character and conditions of interior forests, a critical habitat for many native yet uncommon species. However, little is known about what constitutes an edge effect in any given woodland, so it is worth periodically assessing conditions developing as a consequence of the criteria imposed by the GIN’s fixed constraints.

At each woodland, transects across each hub were sampled to understand changes in overstory composition and stocking density using a 10BAF cruising prism, where samples from three prism points were averaged approximately every 150 ft along each transect. Position along each transect was characterized using distance to the nearest canopy edge. Thus, analysis allowed exploration about whether there was evidence of compositional or structural differences associated with different hubs, different transects, and distance from the edge (Figure 8). What we sought to detect was a difference in stem density or composition associated with some distance from the edge of canopy across different hubs.

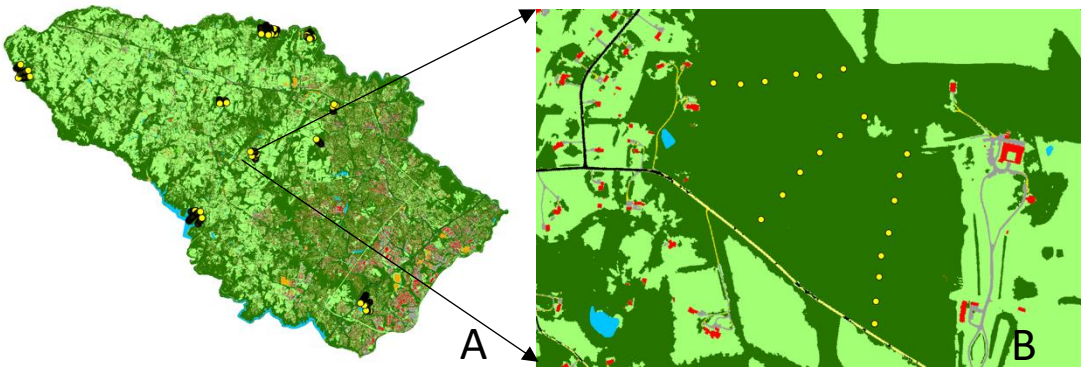

Figure 8. Map of land cover in Howard County, Maryland showing locations of GIN Hub survey transects as yellow points (A) and a close-up view of sampling points traversing canopy at one hub location (B).

Compositional overlap among samples was estimated using Bray-Curtis dissimilarity. Dissimilarity was used to drive a hierarchical clustering operation using Ward's method and ordination using Nonmetric Multidimensional Scaling (NMS). NMS is a form of ordination that seeks to graphically represent dissimilarity among samples faithfully in low (i.e., 2-3) dimensional space so that the distance between any two sample points is proportionate to the degree of dissimilarity in species composition. Clustering identified samples with similar species composition, whereas ordination was used to assess the relative similarity or differences among all samples. Structural differences were assessed using average stem counts from prism points, an estimate of basal area per acre, using Non-parametric Changepoint Analysis (nCPA) (Figure 9). nCPA finds a binary split that maximizes change from one side to the other of an environmental gradient, then assesses uncertainty surrounding the location of the change with a bootstrap resampling procedure. Resampling generated a distribution of change point locations given different samples. A broader distribution indicates greater uncertainty about the location of the underlying change.

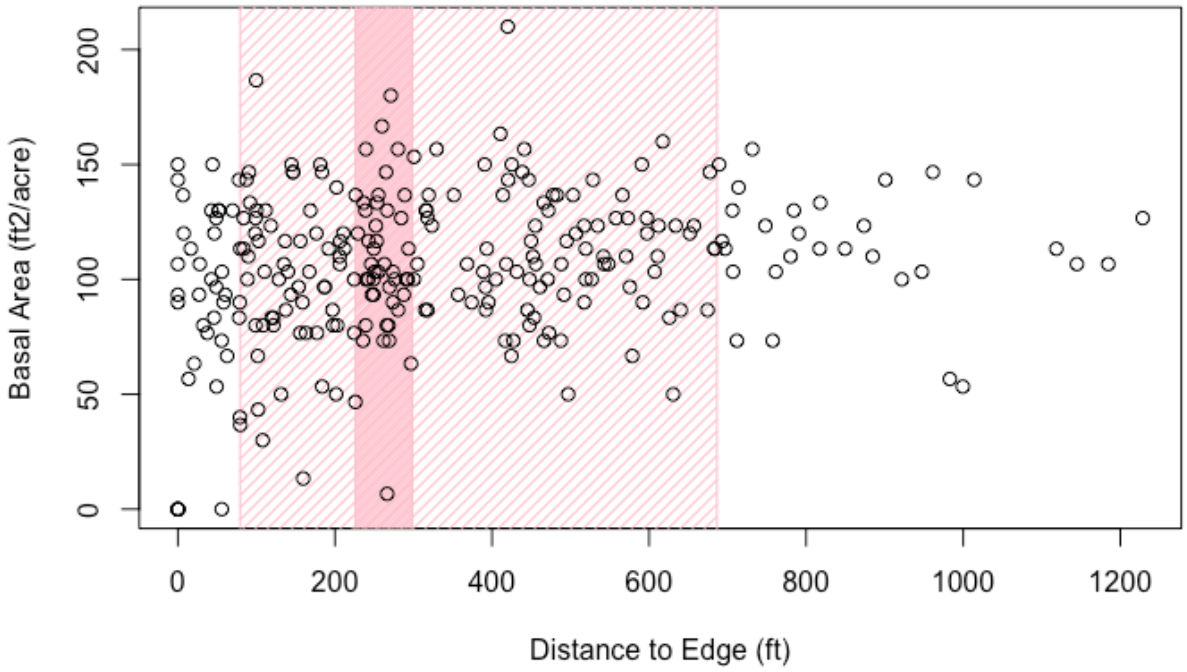

Figure 9. Non-parametric changepoint analysis of structural response to GIN hub edges in Howard County, Maryland. The observed change point at 226 ft was bounded by an inter-quartile range (IQR) from 226 ft to 298 ft, whereas the 95% confidence interval (CI) ranged from 79 ft to 686 ft. The pattern of bootstrapped change points indicated that most of the replicates found a structural difference between 200-300 ft from the canopy edge. This break resulted in an average increase in basal areas from 100 ft^2 per acre to over 111 ft^2 per acre.

nCPA identified evidence for a structural difference in overstory stem density associated with approximately 225-300 ft from woodland edges. Basal area per acre appeared to increase by more than 10% on average once this distance was surpassed.

By contrast, compositional analysis suggested that sample site locations (i.e., at a specific hub) had more in common in terms of overstory species composition than samples at similar distances from canopy edges in different hubs. Hierarchical clustering revealed 9 groups that were strongly associated with hub groupings, whereas distance to edge as a factor controlling composition appeared to vary across clusters, sometimes showing strong within-hub gradients, and other times less so (Figure 10). Cluster dendrograms illustrated the relative similarity of samples based on species composition. More similar samples were grouped into clusters at lower levels in the figures, whereas more distinct samples were only included at higher levels. Blocks of color among sites suggested that sites lumped together by some attribute (in this case hub location versus distance from the edge) also exhibited similar species compositions. The result suggested that there was limited evidence for generic compositional shifts in overstory trees as one moves from edge to interior, but that this was more dependent upon site.

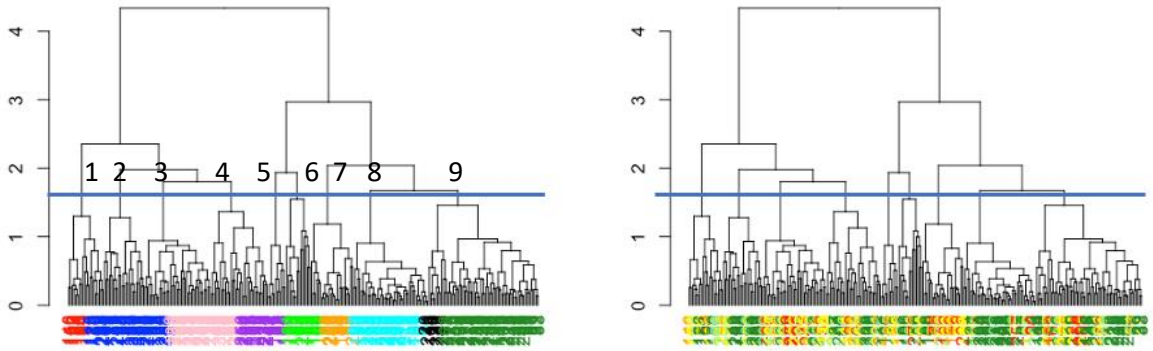

Figure 10. Hierarchical cluster analysis of prism-point overstory samples from GIN hubs in Howard County, Maryland showing strong affinity for colored hub locations (A) and less of a clear association with different distances (i.e., red <50 ft, 50-150 ft, 150-250 ft, >250 ft green) from canopy edge (B). Blue lines and numbers represent a grouping of samples selected for further analysis in Figure 11 and 12.

Ordination of prism point composition across cluster groups underscored strong similarity among most samples as overlap in species space, as did a breakdown of relative dominance across clusters (Figure 11). In general, most transects shared a few predominant species and differences among clusters were largely driven by overstory sub-dominants and associates.

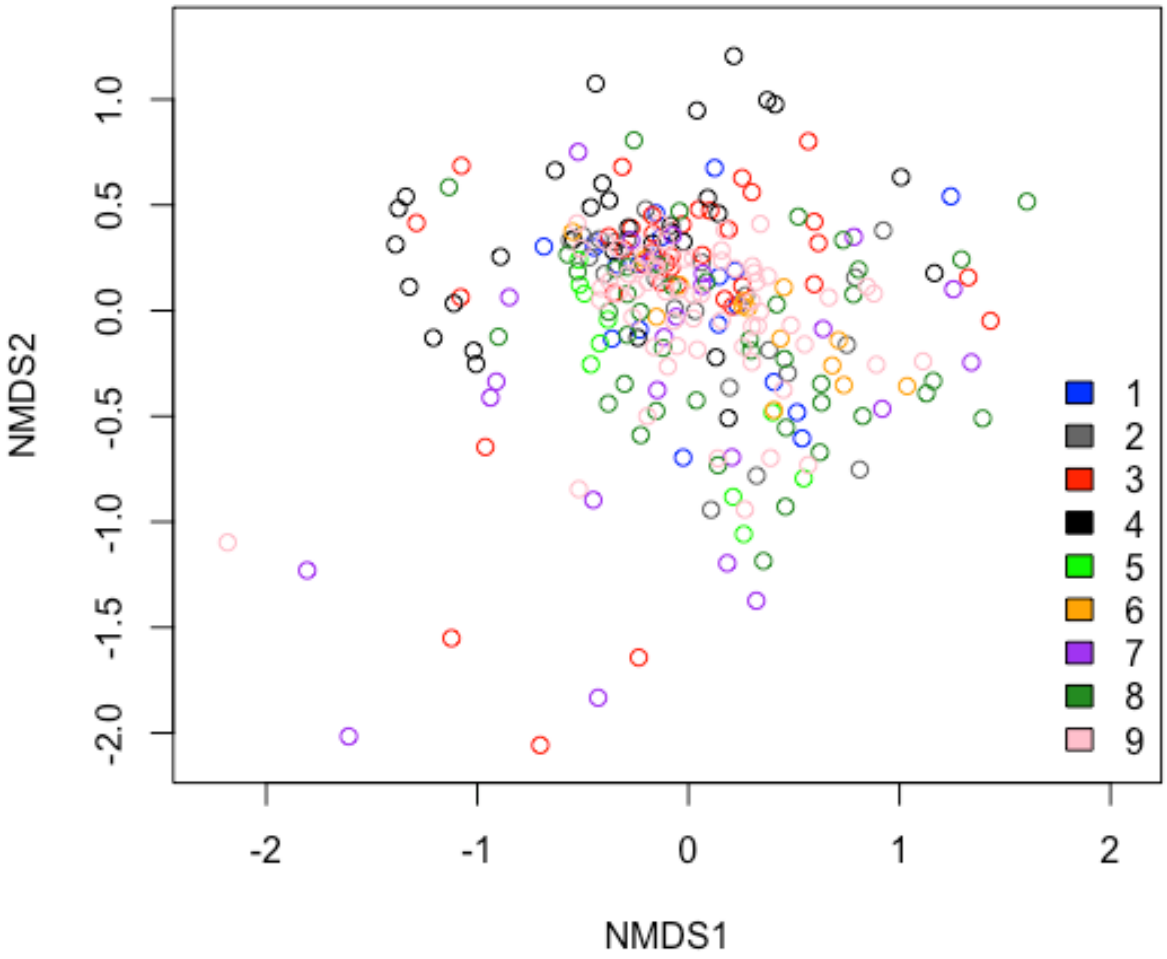

Figure 11. Non-metric multi-dimensional scaling ordination of prism-point transect sample groups across GIN Hubs in Howard County, Maryland. In this ordination, the distance between two points is an indication of their compositional similarity. Nine groups identified by hierarchical clustering are colored to highlight their association or lack thereof in species space. If the clusters were compositionally distinct, they would group together and largely separate from the other colors. All such ordinations attempt to faithfully reduce the number of dimensions of species abundance to two or three. Lack of distinct structure in the plot is likely a reflection of subtle differences between many of the plots with several dominant species in common among cluster groups.

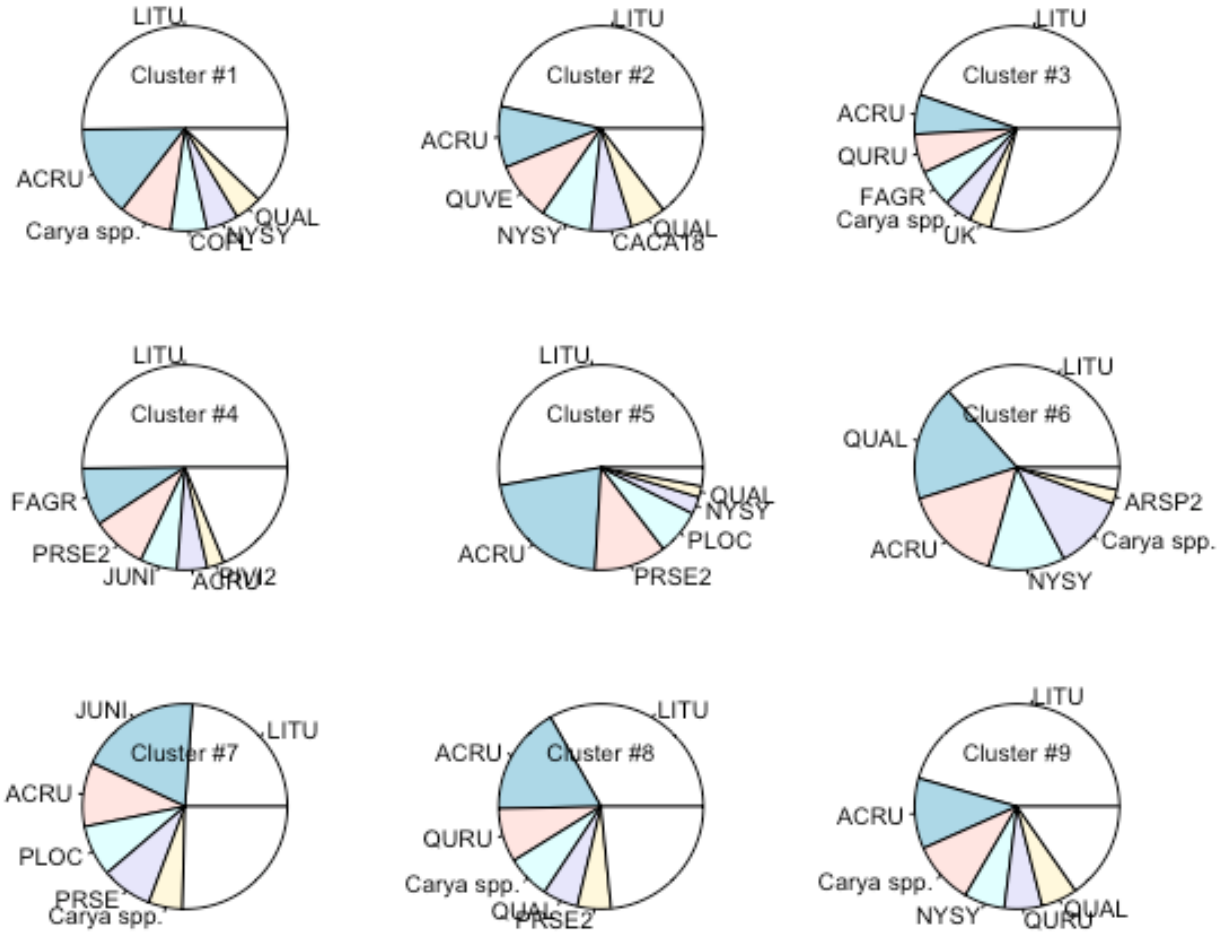

Figure 12. Relative dominance of nine overstory clusters from GIN Hubs in Howard County Maryland is depicted using pie charts. Common species codes include Tulip Poplar (LITU), Red Maple (ACRU), American Beech (FAGR), Black Walnut (JUNI), Red and White Oaks (QURU, QUAL), Black Cherry (PRSE2), Blackgum (NYSY), Sycamore (PLOC), and Hickories (Carya spp). Cluster numbers refer to the numbers in Figure 10 and Figure 11. Blank portions of pie charts represent the relative dominance of remaining, less common tree species.

With so much compositional overlap and predominance of just a few species, distinguishing edge effects within sample composition would require a longer temporal window and/or a larger sample size to allow for the selection of species based on varying disturbance regimes. Further, the predominance of Tulip Poplar, a fast-growing tree intolerant of understory conditions, indicated that many of the County's woodlands remain in early to middle stages of succession, emphasizing that human manipulation in Howard County has a stronger and more immediate impact on what woodlands occur along edges than natural processes. On the other hand, there did seem to be some structural evidence supporting a 300 ft buffer to ensure interior conditions are preserved within GIN Hubs.

Conclusions and Recommendations

High resolution land cover maps have now allowed several precise quantifications of canopy cover in Howard County, Maryland. As methods for producing such maps are refined, it will become easier to track changes to both canopy and interior forests across the County, and to assess trends in these metrics as canopies and human populations grow. We recommend revisiting these and similar analyses once additional land cover maps from post-2018 imagery have been finalized and focusing on a more conservative definition of forests in future retrospective trend assessments. We further suggest that integrating canopy cover assessments with landform and topographic position would also be useful and informative for understanding their relationship to soil formation and the likely successional trajectory of conservation and restoration efforts in and around the GIN. Further, such analysis may enable improved evaluation of runoff generation as well as carbon sequestration and temperature mitigation.

Appendix: Detailed Methods

These methods are provided to document how the results were obtained and to facilitate future reproduction of similar results for 2018 data and beyond. They are written assuming a particular level of familiarity with geospatial and analytical methods but with an effort to minimize use of technical jargon.

Objective 1:

1A: Assess County-level tree canopy and area available for planting

- Input layers: (1) county polygon, (2) “landcover change” raster for 2013-2018
- Computed area of county boundary in acres
    - Reprojected polygon and raster to align with County boundary in NAD 83 stateplane, with pixel size remaining 3.28 ft (1m), with county boundary as mask
- Reclassed change product to 2013 and 2018 aggregated landcover, with polygon as mask
- Landcover classes: 1. Water, 2. Emergent wetlands (absent), 3. Canopy, 4. Scrub/shrub, 5. Herbaceous, 6. Barren, 7. Structures, 8. Impervious, 9. Roads, 10. Canopy over structures, 11. Canopy over impervious, 12. Canopy over roads.
    - The change product has a more complicated set of codes describing the above categories as well as transitions between classes over time.
    - For example, the reclass operation created existing tree canopy for 2013 as class 33 (canopy in both time periods) and any other class starting with 3 (e.g., 36) which would indicate tree canopy in 2013 that transitioned to something else in 2018.
    - Likewise, the 2018 tree canopy was defined as class 33 and any class that ended in 3 (e.g., 63), indicating a transition from something else to tree canopy over time.

- Aggregate classes for each year included:
    - existing tree canopy (*existTC*) consisting of the canopy class (3)
    - possible tree canopy (*possTC*) consisting of shrubs (4), low vegetation (5), and barren (6) classes
    - possible impervious tree canopy (*pimpTC*) consisting of impervious surfaces (8) and canopy over impervious surface (11)
    - land cover not suitable for planting (*notSuit*) consisting of structures (7), roads (9), canopy over structures (10), and canopy over roads (12)
- Reclassed 2013 and 2018 total canopy, with County polygon as mask, from land cover class 3, 10, 11, and 12 in each year
- Tabulated area of each land cover class for county zone
    - Calculated number of $1m^2$ pixels in 2013 layer as *existTC* and Soft Canopy
    - Combined Canopy over structures, impervious surface and roads as Hard Canopy
    - Combined Hard and Soft Canopy as Total Tree Canopy (TTC)
    - Combined shrub/scrub, low vegetation, and barren classes as *possTC*
    - Combined impervious and canopy over impervious classes as *pimpTC*
- Combined water, emergent wetland (this was not present in HOCO), roads, structures, and canopy over roads and structures as *NotSuit*
- Calculated overall acreages as well as percentages for county
- Produced individual layer

1B: Assess County-level Forest cover

- Created unique ID numbers for each patch of soft canopy using *RegionGroup*() function
- Inverted soft canopy layer (i.e., pixels with no canopy become 1 and pixels with canopy become NoData) as a "source grid" for distance mapping
- Created a unit map (entire county with value of 1) as "cost surface"
- Mapped cost-distance from canopy edge across cost surface to obtain "distance from edge" map for every soft canopy pixel
- Calculated zonal maximum of distance to edge, with unique RegionGroup IDs as zones
- Estimated extent of each RegionGroup using ZonalArea function to compute patch size
- Using a conditional statement (i.e., Con), selected all soft canopy RegionGroup pixels meeting maximum distance >17.5 (for thickness >=35 ft) and areal (>=10,000 ft^2) criteria as "forest" as 1, with other pixels 0
- Tabulated area of forest class for county
- Calculated overall forest, soft canopy, and total canopy cover percentages for county
- Produce individual layer

Objective 2:

- Input layers: (1) county polygon, (2) reclassified landcover raster for 2013, (3) forest layer, (4) County property layer (i.e., tax parcel map)

2A Assess Parcel-level tree canopy and area available for planting (possTC, pimpTC)

- Using County parcels as the zonal input, tabulated area of reclassified land cover classes masked by the county boundary as a table
- Summarized output table to compute proportions and percentages
- Joined output table to parcel feature attribute table (may be provided separately)

2B Assess Parcel-level forest cover

- Using county parcels as the zonal input, tabulated area of binary forest layer masked by the county boundary as a table
- Summarized output table to compute proportions and percentages
- Joined output table to parcel feature attribute table (may be provided separately)

2C Non-Profit TC Potential:

- This data was produced as a byproduct of 2A and 2B but not discussed in the report
- To obtain, subset attribute table of parcel level summary using definition query to isolate exempt parcels
- Then select by owner in further definition query to identify parcels not owned by county or municipality

2D Tree Canopy Summary by Land Use:

- Rasterized parcel layer using designated land use as cell value, snapped to land cover raster to ensure planar enforcement (because prior analysis revealed overlapping duplicate polygons, adjacent polygons with poor boundary tolerance, and because summary of parcel proportions revealed areal inconsistencies)
- Reclassified land use raster to simplify categories to agricultural, commercial, exempt, industrial, residential
- Included all NoData ownership (presumed County) as exempt
- Performed tabulate area using reclassified land use raster as zones, reclassified land cover raster as value
- Performed a similar tabulate area operation using reclassified land use raster as zones, binary forest cover raster as value
- Summarized output tables for plotting

Objective 3: Create “negative green infrastructure” layer showing available planting space in GIN Hubs and Corridors

- Selected all parcels with a designated ‘Agricultural’ land use from property layer
- Selected all properties owned utility companies (electric/gas, telecom, railway) using DESCCIUSE field
- Buffered water mains, pressure sewers, gravity sewers, minor streamlines, ponds, lakes, dams, and major stream polygons by 10 ft
- Included paved and gravel road layers from County
- Isolated structures from 2018 landcover raster, vectorized, and buffered by 30 feet
- Isolated canopy from 2018 landcover and vectorized
- Compute the geometric union of all polygons into soft canopy, linear features, and areal polygon layers
- Dissolved polygons in each above layer into a single feature
- Erased area of dissolved polygon layers from GIN Hub and Corridor polygons
- Removed sliver polygons and small flecks as convenient
- Provided County level layers indicating unplantable space and remaining “negative” GIN features as plantable areas

Objective 4: Assess impact of woodland hub configuration within the GIN on the composition and structure of overstory stems

- Identified hubs and their boundaries using maps provided by Howard County
- Selected hubs to represent geographic dispersal across county, a mixture of upland and valley settings, size, and spatial configuration
- At each hub, established 3-5 transects >450 ft apart traversing both edge and interior habitats at locations representing hub central cores and thinner extensions
- Along each transect, establish a sampling location every ~150 ft with a low-grade GPS and collect 3 prism points at each location, noting overstory species, Shumaker vine invasion scale (0-5 where 0 is no vines and 5 is canopy completely engulfed) for each stem, and dominant ground cover
- Average prism points, Shumaker scores, and stem count at each sampling location
- Extract distance to canopy edge for each sampling point
- Create a site by species matrix
- Perform nonparametric changepoint analysis (nCPA) on stem density along a distance gradient
- Perform Wards hierarchical clustering of bray-Curtis dissimilarity on species matrix
- Assess clusters by distance to edge and site location
- Summarize relative dominance of overstory species by clusters
- Database provided for future/additional analysis