Technologies for Metro Nature Health Benefits Mapping

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EXECUTIVE SUMMARY

Project Purpose and Objectives

Urban forests and other urban greening environments provide ecosystem services. This project contributes to development of a benefits assessment tool - greenHEAL - that can be used to determine the human health and well-being benefits provided by city trees, parks, gardens, and open spaces. A trio of efforts will be eventually be combined to create greenHEAL: 1) evidence of health and well-being benefits, 2) economic valuation, and 3) spatial and map analysis.

A prior project has compiled the research literature, building a collection of more than 2,800 scientific publications. Summaries of this 40-year span of studies are at the Green Cities: Good Health web site. Now underway is a study to translate these health and well-being benefits to economic value. Using both market-based and non-market valuation approaches a team of economists and social scientists are developing theoretical and practical estimations of urban greening contributions to community health.

This report describes the project team’s effort to jump-start the third component that is needed to create a greenHEAL assessment tool. We explored the potential map-based, spatially explicit approaches to determine the locations, proximities, and spatial relationships of urban nature, human populations, and benefit levels. This project included literature reviews (about nature and health, and urban vegetation mapping), contacts of key professionals to learn about local government mapping resources, and exploration of preliminary techniques for determining vegetation character and distribution across a city or metropolitan area.

Metro Nature and Human Health

Metro nature is an inclusive term that describes the diversity of nearby nature in cities that contributes to the quality of everyday lives of urban residents, and supports livability on multiple levels. The Green Cities: Good Health web site is a review of publications about the relationship between urban greening and human health and well-being. The literature search revealed more than a dozen themes of services and benefits, supported by of more than 2,800 scholarly publications. This evidence base spans nearly 40 years and includes the contributions of multiple disciplines, including various social sciences, epidemiology, and public health. A thematic framework of the benefits and supporting research evidence is provided.
Geospatial Data and Tools
The relationship of health benefit to vegetation features presents challenges for building an assessment tool: diversity of urban vegetation structure, heterogeneity of vegetation distribution, and the importance of associations with specific land uses. While GIS is a widely used tool for local governments to record and analyze local spatial data and records of land use, tax parcels, and infrastructure, the data layers and structure are not uniformly complete or accurate from one city to another. Representation of a city’s parks and vegetation is often even less complete.

GIS systems make use of vector data, recording features on the ground as points, lines or polygons. Raster datasets are composed of continuous grids of pixels provided by remote sensing using passive (such as aerial photography or satellite scans) or active data collection (such as LiDAR). Raster data can be analyzed to highlight key characteristics of vegetation, including urban 'understory' vegetation such as the more finely detailed conditions of parks, gardens, and community gardens. These conversions, achieved using specialized software, have been used for urban tree canopy analysis, and this project explored the feasibility of LiDAR analysis for ground level vegetation. Analysis products become GIS layers that can then be combined or compared with/to other locational data in a city.

Connecting Vegetation to Benefits
The report then turned to the central purpose of the project, how to analyze the critical vegetation features in the urban environment that relate to human health and wellness. Details about the data and processing are described, including how tree canopy information is derived. Use of LiDAR as a tool to detect ground level garden and understory conditions was explored and results are reported here. The feasibility of this approach is discussed considering the geospatial resources that are actually available for several U.S. cities.

Recommendations
The proposed greenHEAL tool represents a major innovation in urban forestry benefits analysis. Map-based benefits display and analysis is not easy, but recent breakthroughs in remote sensing and geospatial data capture and processing now make this project concept feasible at reasonable cost. For instance, the analysis described here was completed on a budget of $9,500. These are the next steps to develop an urgently important greenHEAL assessment tool:

- health benefits impacts evaluation and prioritization
- expand and refine the greenHEAL benefits analysis
- streamline analysis and model processing
- review candidates for metro region case study(s)
PROJECT PURPOSE & OBJECTIVES

This report considers the opportunities to combine remote sensing and GIS (Geographic Information Systems) applications to conduct regional or metro area assessments of vegetation extent and character, as it relates to human health and well-being. The vegetative cover(s) of interest are the heterogeneous, multi-layer landscapes (including urban forest canopy, parks, gardens, and open spaces) that have been empirically associated with human health, therapy, and wellness. The differentiation of vegetation based on human health benefits differs with regard to scale and texture depending on land use (e.g. residential versus hospitals) and the character of human encounter that produces benefit. This report is a feasibility exploration of concepts, tools, and potential modeling that combines current research, best practices, and geospatial datasets or GIS layers.

Nature-Based Health Benefits

Nearly four decades of social science research documents an extensive array of human health and well-being benefits that are generated by the human experience of nature within built environments. A prior project has compiled the research literature. More than 2,800 scientific publications report the evidence of benefits provided by city trees, parks, gardens and open spaces. These benefits accrue at all social scales: individual, household, neighborhood, community, and citywide. This work has been compiled and is being made available at the Green Cities: Good Health web site.

Now underway is a study to translate these health and well-being benefits to economic value. Using both market-based and non-market valuation approaches a team of economists and social scientists (at University of Washington and Mississippi State University) are developing theoretical and practical estimations of the economic consequences of urban greening contributions to human health.¹

Tools for Benefits Analysis

Perhaps better known is the research about the environmental benefits (e.g., air and water quality, stormwater management, climate effects) that are associated with urban forest canopy and urban greening. The science has been converted to i-Tree benefits models that are now available to the public from the USDA Forest Service. Current i-Tree modules provide ecosystem services analysis based on city tree and canopy data inputs, and include economic valuations. The analysis algorithms largely focus on biophysical benefits and functions. The only representation of socio-cultural benefits is market analysis of residential property values and air quality response.

¹ Funding provided by the USDA Forest Service on recommendation of the National Urban and Community Forestry Advisory Council, with additional support from the USDA Forest Service, Pacific Northwest Research Station.
This is a major omission, as policy-makers and the public have shown that they also find social benefits of urban forestry to be compelling.

This report describes initial efforts to develop a greenHEAL analysis model, which would complement other i-Tree modules. These elements may eventually be combined to create greenHEAL: 1) evidence of health and well-being benefits, 2) economic valuation of benefits, and 3) spatial and map analysis to geolocate vegetation from which benefits are derived. greenHEAL, as a benefits assessment tool, would be used to determine the human health and well-being potential provided by city trees, parks, gardens and open spaces across an entire city. Just as i-Tree projects scale up the evidence about benefits of single or small groves of trees to broad canopy areas, so too can health benefits that result from the experience of trees and nature at a home, office, school, or hospital be scaled up to larger geographic areas.

Exploring Geospatial Representation of Nature-Based Health Benefits

This report describes the first explorations for the third component of greenHEAL, that is the development of a map-based, spatially explicit approach to determine the locations, proximities, and spatial relationships of urban nature, human populations, land uses, and health benefit levels. The project team explored the feasibility of conducting urban vegetation assessments using remote sensing, municipal GIS layers, and geospatial analysis tools. The project work included literature reviews (about nature and health, and urban vegetation mapping), contacts of key professionals to learn about local government map resources, and exploration of preliminary techniques for determining vegetation character and distribution. The next phase of this project will be to work toward integrating geocoded data (probably using GIS) with benefits evidence economic valuation. These initial ideas, and iterative proof of concept will be used to support additional funding requests for work on a fully functioning greenHEAL assessment tool.

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1 This is a working title for the product. Other suggestions have been i-Tree Health, and i-Tree Anthro. A final name for the tool should acknowledge that human health benefits are derived from a variety of nearby nature settings in cities, in addition to the urban forest.
METRO NATURE & PUBLIC HEALTH

Metro nature\(^\text{ii}\) contributes to the quality of everyday lives of urban residents, and supports livability on multiple levels. The Green Cities: Good Health web site is a review of publications about the relationship between urban greening and human health and well-being. The literature search revealed more than a dozen themes of services and benefits, supported by of more than 2,800 scholarly publications (most being peer-reviewed). This evidence base spans nearly 40 years and includes the contributions of multiple disciplines, including various social sciences, epidemiology, and public health\(^\text{ii}\). Many metro nature services are provided by small-scale nearby nature in neighborhoods and communities, and may be below consciousness of individuals. Assessments of the potential economic values provided by such services have been limited\(^3\), but are now underway\(^4\).

A Framework of Metro Nature and Human Health Benefits

Figure 1 is a thematic framework that summarizes the array of services and benefits based on the Green Cities: Good Health findings.

*Environmental fitness* is the baseline condition of environmental support for human health. The best practices and systems of a sanitary city provide the most basic conditions necessary for good health for all city residents, such as clean air and water, and the absence of toxins\(^5\). Environmental protection agencies at the national and state level attempt to monitor and regulate the potential harmful impacts of pollutant emissions, harmful materials dumping, and industrial and agricultural by-products. Urban forests and green infrastructure are increasingly utilized as a prevention or mitigation strategy in both regulatory and voluntary efforts to sustain healthful environments within cities.

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\(^{\text{ii}}\) The term ‘metro nature’ is used here to refer to the collective opportunities for human nature experiences that improve urban livability (Wolf, 2008). It is inclusive of both the diverse nature conditions found in cities, as well as representing the diverse public health and social science disciplines that have contributed research evidence about nearby nature for human health and well-being. Metro nature includes endemic ecosystems, such as urban forests, greenbelts, conserved open spaces, and riparian corridors that may be patch or relic expressions of native ecological associations. It also includes culturally constructed nature such as parks, streetscapes, community gardens, pocket parks, and recreation paths, as well as structural innovations that are integrated within built form to serve specific functions, such as green roofs, green walls, or green infrastructure facilities.

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**METRO NATURE HEALTH BENEFITS MAPPING**

*Wellness support* represents a less fundamental, but no less important urban condition. Many cities have gray infrastructure systems that support hygiene and basic human welfare (such as potable water and sewage treatment systems). In addition, research of recent decades indicates that having ubiquitous green systems such as parks, community gardens, trees, and green spaces provides supplemental benefits. Convenient and pervasive access to nearby nature includes passive views from home and vehicle, green spaces within walkable distances, and active encounters with nature (such as gardening and tree planting) that appear to provide wellness support. Beneficial human response includes physical activity that can reduce incidence of chronic diseases, reduced physiological stress, and improved mental health, such as increased attention restoration and reduced depression. Having nearby green space within the general extent of one’s neighborhood is associated with positive outcomes across the human life course. For instance, urban forest canopy proximate to households has been associated with higher infant birth weight⁶, and green urban neighborhoods with reductions in elder mortality⁷.

*Supportive spaces and healing places* represent settings that heighten human performance and function. Common to the human experience of cities are facilities and institutions where one conducts routine activities (such as going to school or work). One also pursues intermittent services or assistance, such as medical care or therapy. Studies have found that nature is supportive in human performance situations, such as reduced workplace absenteeism (Kaplan 1993⁸) and high school success (Matsuoka 2010⁹). A more extensive literature indicates that both passive experiences of nature and the directed activity of horticulture therapy can aid people in both physical and emotional healing. Green elements that support people in specific settings or aid in healing or therapy are often dedicated, constructed spaces and may include specific design elements that engage people to achieve specified experiences or outcomes. Such places include healing gardens within hospitals, horticulture therapy gardens, and sacred spaces (such as memorials). In contrast, supportive spaces are the expressions of nature that are adjacent to and augment places where people work, learn, or study; they provide benefits but not necessarily with the direct intention of healing spaces.

*Amenity and aesthetics* describe perhaps the most widely perceived benefit of trees, parks, and greening. While urban greening initiatives are ever more frequently premised on environmental benefits, the term ‘beautification’ is commonly used in public programs and appeals for greening support. Many in the green industry rely on client appeals of emotion and beauty (such as LoveYourLandscape.com). The City of Seattle’s Releaf program conducted marketing research to develop residential outreach to boost canopy cover; citizen responses of beauty, wonder, and spiritual connection to trees were more common than responses of environmental services¹⁰. Research indicates that humans respond to the presence of nature in profound ways, even after only brief exposure times, though they may not be directly aware of outcomes. Neuroscience studies are considering the role of urban environmental influences on human wellness¹¹.
Finally, the term community acknowledges that all of these experiences and associated services are embedded within the context of place and change. Due to local government commitments to sustainability and participatory urban planning, citizens are becoming ever more involved in urban greening planning, implementation, and management. In resurgent cities cleaning up vacant lots, restoring parks, and creating community gardens are often markers of community recovery. These acts of civic ecology can lead to social engagement and cohesion, perhaps improving local social resilience. Studies that address neighborhoods or general human populations suggest that nature-based activity develops the social foundations that can support disaster recovery. Having adequate, and well-managed landscapes and natural capital are associated with greater neighborhood satisfaction and social cohesion, reduced incivilities and crime. Additional studies point to the unequal distribution of parks and natural resources within cities and its environmental justice implications.

**LINKING NATURE & BENEFITS :: CHALLENGES**

Table 1 is a summary of the land use settings and vegetation elements that provide benefit. Generally, the vegetation or environmental condition is of greater scale or area cover at the top of the table. As one moves down the rows the nature spaces become smaller, and benefit is ever more dependent on careful design and planting. This quick overview immediately reveals certain challenges for geospatial analysis of metro nature and human health, that is, analysis approaches must evaluate both vegetation and social conditions.

**Table 1: Land Use Settings and Vegetation Elements Associated with Metro Nature Benefits**

<table>
<thead>
<tr>
<th>Benefit</th>
<th>Land Use &amp; Context</th>
<th>Greening &amp; Vegetation</th>
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<tr>
<td>Environmental Fitness</td>
<td>known presence of harmful materials, point source emissions, or manufacturing by-products; often associated with commercial and industrial land uses; brownfields</td>
<td>highly disturbed landscapes, residual toxic materials posing risk, impervious surfaces</td>
</tr>
<tr>
<td>Wellness Support</td>
<td>residential areas; walkable communities; equitable access</td>
<td>proximate tree canopy, large and small parks/gardens, street trees and tree lawns</td>
</tr>
<tr>
<td>Supportive Spaces</td>
<td>office deskworkers, major transportation corridors (green roadsides providing restorative settings); school/college campuses</td>
<td>trees, gardens and landscapes proximate to office settings; landscaped roadsides; campus landscapes</td>
</tr>
<tr>
<td>Healing Places</td>
<td>hospitals, rehabilitation and recovery centers, clinics, elder care facilities (particularly for dementia patients)</td>
<td>trees and gardens proximate to facilities; facilities for horticulture therapy</td>
</tr>
<tr>
<td>Community</td>
<td>places of social interaction within residential settings; restored vacant lots</td>
<td>parks with social spaces; community gardens; restoration sites having stewardship projects</td>
</tr>
</tbody>
</table>
**Challenge :: Diversity of Vegetation Structure**

Across the scientific literature of metro nature and human health, one sees that specific vegetation features are associated with specific health and well-being outcomes. The pristine forest landscapes include multiple vegetation layers, such as overstory, multiple understory levels, and ground level vegetation; metro nature has similar complexity. For instance, Figure 2 shows the range of vegetation character that is associated with diverse benefits in school settings. To date, most vegetation assessment associated with human health and well-being benefits at the citywide scale has focused on the presence of parks (and their relative proximity to residences), or an estimation of tree canopy. Yet much of the benefits evidence indicates the importance of lower height vegetation (small trees, shrubs, and ground cover), as this is the vegetation that a person interacts with at eye height.

**Figure 2:** Vegetation is associated with positive response on school campuses. Depicting school sites, these images are an example of the diverse vegetation conditions of metro nature that are associated with potential human health and well-being benefits.

**Challenge :: Heterogeneity of Vegetation Distribution**

A second complication is the heterogeneous character of the vegetation that generates human health and well being benefit. In other words, research indicates that humans experience benefit from plants and gardens ranging from a single large tree, to urban forest canopy, to roadside vegetation, to highly designed small gardens. Any effort to both identify and map the vegetation of a city will probably be an iterative process, building from any existing datasets and launching next steps based on data availability, technical capacity and cost.

**Challenge :: Association with Land Uses**

A final challenge is the degree to which GIS data layers are available that locate the land uses or settings where benefits may occur. Certain benefits are associated with specific land uses. While many of the studies focus on
residential settings, a substantial amount of research addresses other life situations, such as work, school, and healing settings (particularly hospitals). Certain health, well-being and wellness outcomes are dependent on land use or zoning context; for instance workers in office buildings may experience improved job performance if nearby nature is available, and hospital patients can benefit from having healing gardens within the facility. While GIS has become the widely accepted replacement for paper maps, local government records of zoning, land use, tax parcels, and parks are not uniformly complete or accurate.

GEOSPATIAL DATA & TOOLS

Geospatial representation of the world is ever more common as computer-based tools have become more efficient and less expensive. Location-based technologies enable entities – from individual persons to entire nations – to construct representations of the world having, 2D, 3D, and temporal dimensions. The combination of “big data” and digital mapping are changing how people and societies think, behave, and interact.

Looking forward to a future assessment and monitoring tool that integrates metro nature across a city or metropolitan region there are specific datasets, processing technologies, and products that will be needed. This section introduces fundamental ideas and applications, with occasional application to greenHEAL.

GIS in Local Government

GIS has become the standard tool for local governments to catalog parcel and infrastructure data. It facilitates layered analysis of the spatial relationships of citizens and the goods and services that sustain them in the urban environment. Most cities now use GIS to produce and catalog map layers that aid planning and management of the key systems and services within cities. GIS platforms are spatial databases that link thematic or graphic maps with tabular data or attributes of the mapped features. GIS allows users to manage, analyze, and display a wide variety of geographically referenced information. Mapped data can be displayed as point, line or polygon vectors, or as continuous data known as rasters.

Raster and Vector Data Formats

The key difference between GIS map layers and most remote sensing imagery is that GIS map layers contain point, line, or polygon vectors with more or less complete attributes tables connected to each vector. Most remote sensing data are in the form of rasters, structured as a continuous grid of pixels. Each pixel has values attached to it (for examples, color information or elevation).
Vector layer features may be considered as geometrical shapes, and may be seen as similar in appearance to traditional maps or a printed atlas. Points note simple locations. Lines denote linear features, such as roads or rivers. Line features can indicate distance. Polygons describe areas, such as lakes, or property or state boundaries. Polygons features can be measured for area or perimeter. In the vector’s attributes table, each feature has a row with location and an unlimited number of additional attributes. For example, a property polygon might have information on ownerships, street address, existing structures, zoning, tax liability, and other characteristics.

Rasters are composed of a continuous grid of pixels and are most useful for displaying continuous data. Each pixel in the raster has discrete values attached to it. In imagery, such as aerial photography, each pixel holds its color information as a building block of the image. However, other continuous data, such as elevation or temperature, are also commonly displayed using rasters. Each pixel’s value, while displayed as a color or tone, actually conveys its relative value within the entire range of the raster data. Often, remote sensing analysis seeks to translate these raster datasets and develop either meaningful new vector layers or new rasters with additional information.

Raster data is usually accessed from remote sensing sources. It may be publicly available, or generated by contract with a firm. The translation of raster to vector layers often requires advanced analysis and specialized software. Raster datasets can be large size, owing to the richness of primary data collection and high detail. Some cities retain datasets about vegetation. For example, the City of Seattle has archived spectral imagery (3 and 4-band color and infrared aerial photography) for 2006, 2009, and 2011 that was accessed from NAIP (National Agricultural Inventory Program). The city also has LiDAR data (flown by King County in 2009, available through the Puget Sound LiDAR Consortium).

Remote Sensing Overview

Remote sensing describes a collection of techniques for gathering geospatial data without touching the subject. The American Society for Photogrammetry and Remote Sensing offers this definition, "The art, science and technology of obtaining reliable information about physical objects and the environment, through the process of recording, measuring, and interpreting imagery and digital representations of energy patterns derived from non-contact sensor systems".

Remote sensing technologies can be differentiated between passive and active types. The distinction between passive and active methods can be illustrated by the difference between taking a daylight photograph and a flash photograph. The daylight photo collects and records the available light energy, the passive mode. The flash photo collects and records the light energy reflected by the subject from the flash the camera has sent out.
Passive methods gather electromagnetic energy from the Sun that returns from the Earth’s surface. Aerial photography and Landsat satellite imagery are examples. Agricultural inventory programs collected black and white aerial photographs beginning in the 1940s. Contemporary satellite data collection includes infrared and thermal spectral imagery in addition to the visible spectrum. Data from outside the visual spectrum offer scientists and managers important ways of “seeing” and studying the environment.

Active methods measure the returns of energy waves emitted from a sensor. The possible energy sources depend on the specific features and the scale of the landscape to be analyzed. RADAR (for Radio Detection And Ranging) uses radio wave energy and can gather information at large scales and coarser resolutions. SONAR (originally Sound Navigation And Ranging) uses longer wave sound energy, and is most often used in water. LiDAR (Light Detection And Ranging) emits laser light toward the landscape or features of interest, and measures the timing and intensity of the returns. LiDAR accurately captures elevation and texture of the surfaces, from wide swathes of the Earth’s surface to fine textures of individual trees or minute faults in road surfaces. LiDAR has become increasingly available for urban and suburban areas.

Remote sensing data allows spectral, temporal, and spatial analysis. Each remote sensing technology has inherent limits, which are important to consider when planning a project. Two examples illustrate the intersection of analysis potential and resolution. Landsat satellite imagery has been collected at least several times a year since the 1970s, so it offers high temporal resolution. One can look at landscape scale changes across the years. It also has captured data in and beyond the visual spectrum. But at 30m per pixel resolution, it lacks the detail to “see” objects smaller than 30 m². Aerial LiDAR might only be flown once (or infrequently) over a city. Temporal and spectral analyses are impossible. But at 1m per pixel spatial resolution, much more precise mapping of elevation and landscape features is possible. Advanced analysis tools allow analysts to measure objects in the space from the bare earth to the top of the tree canopy, and include building elevations.

For urban vegetation mapping or classifications an analyst must balance their approach with the choices of the available spatial, spectral, and sometimes temporal resolution data. The complex matrix of built and vegetated features in urban environment poses unique challenges compared to remote sensing in landscapes having fairly uniform plant associations across similar sized study areas (such as commercial forests).

Analysis of remote sensing raster data can generate new raster information or vector layers. Procedures used to do such conversions include object-based image analysis (OBIA), Fusion LiDAR analysis, and GIS 3D and Spatial Analyst programs. Products can include: tree canopy cover maps (including breakouts by zoning types or neighborhoods), additional land use and land cover classification, and identification of pervious versus impervious surfaces. It is important to note that developing and applying automated processes to these classifications and data conversions is not a simple task. But the results can be fairly precise information that reveals conditions...
across an entire metropolitan region without having to do field measurements (though limited field sampling may be needed for accuracy assessments).

**Local Government GIS Layers**

Datasets able to spatially link built elements and infrastructure, the location or patterns of common uses, and the urban vegetation structure and condition are needed to assess potential health benefits or impacts. Vector format maps are generated using manual digitizing input or are converted from raster data (more on this later). City parcel and infrastructure data in municipal GIS database projects have been created in several ways. Paper maps may be scanned into digital formats, georeferenced, and the key polygons, lines, and points can then be hand drawn as layers or shapefiles into a GIS system. Similarly, polygons, lines, and points may be hand drawn onto georeferenced aerial photographs, and into GIS layers or shapefiles. Locations with specific point coordinates including street addresses may be created from tabular data sources. Point locations can be collected in the field as georeferenced coordinates, and key site attributes can also be recorded.

Many cities now make their GIS layers (in vector format) available online, and downloaded files can be viewed using GIS software. Examples of map layers include: parcel data indicating locations, uses, ownerships, addresses; and utilities; roads and transit locations, often using standard classification labels; parks and green spaces, with GIS attributes such as size, location, facilities, amenities; lakes and rivers, including attributes of size, and crossings.

Municipal GIS products are often from a variety of sources. Data about the schools may come from the school district, parks information from the parks department, bus stop locations from the local transit agency, etc. Municipalities seek to coordinate and oversee the quality of the GIS data under their control. Still, multiple sourcing leads to variability in quality and level of detail in a city’s GIS information across different urban interest areas. There is also variety in the available parcel and infrastructure datasets between cities. Some cities public GIS services offer details about the locations and attributes about their parks, green spaces, schools, hospitals, and other locations of supportive services, while others were less well-organized or are less publically available.

**Satellites and Photography – Remote Sensing**

Passively sensed data are most commonly collected by satellite-borne optical sensors, but aerial photography can also be included. Sensors record the intensity of electromagnetic energy reflected back from the Earth’s surface at defined spectral bands between 400nm and 2500nm. Visible light returns occur at approximately 400nm to 700nm. The vegetation that we see as green also reflects large amounts of electromagnetic energy in the near infrared spectrum, from 700nm to over 1300nm. So remote sensing of vegetation frequently uses both the spectral information in the visible and in the near-infrared parts of the spectrum.
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Uses of remote sensing of urban vegetation features with passively gathered data include classifications of impermeable surfaces, green vegetation, and soils, as well as assessments of vegetation health and vigor.

Each sensor’s capability to discern different vegetation related features in the urban environment depends on several important attributes. The sensor’s spectral resolution describes the ability to distinguish different wavelengths of electromagnetic energy within the spectrum. Spatial resolution describes the sensor’s ability to differentiate objects in the horizontal plane. The pixel size of the sensor defines its spatial resolution. Radiometric resolution notes the intensity levels that a sensor can use to record returning radiation. Temporal resolution refers to the number of times a sensor collects data at a specific location.

Contemporary passive optical satellite sensors include high spatial resolution and medium spatial resolution sensors. High resolution sensors include Quickbird (with a 2.4m pixel size) and IKONOS (with a 3.2m pixel). Medium resolution sensors include Landsat TM (30m pixel size) and ASTER (15m to 30m pixel sizes).

The choice of data and methodology used in an urban vegetation assessment is influenced by data costs, data resolution needed, the size of the image area covered, and the spectrum needed. Comparing Quickbird and Landsat TM will illustrate the tradeoffs for two passive satellite-borne sensors. Quickbird offers higher resolution, and, having a band in the near-infrared, it offers an expanded spectral resolution. It passes global locations 2 to 3 times a week, so good temporal resolution also is available for analysis of vegetation change. But Quickbird is a commercial product, and a 10 square mile (~26km²) data delivery will cost approximately $300 per discrete scene (2014 pricing from Digital Globe).

Landsat TM offers medium resolution data. This spatial resolution potentially limits its usefulness for some analysis, but is still useful for many applications. It passes locations approximately every 16 days, and so it also offers good temporal resolution for vegetation change analysis. In some vegetation and urban land cover analysis, the additional short-wave infrared and thermal infrared bands offer critical information that may let researchers discriminate moisture content of vegetation and soil, and map thermally defined features. Landsat imagery is publicly available and free, and users may download large scenes (from the U.S. Geologic Survey).

LIDAR – Remote Sensing

Urban vegetation analysts increasingly use LiDAR, an active form of remote sensing. LiDAR collects information on surfaces by measuring the returns from the surface of narrow beams of near-infrared light. Terrain and vegetation mapping missions primarily collect LiDAR from aircraft (see example in Figure 3). LiDAR data are increasingly collected by public agencies and often publicly available.
LiDAR information is collected using devices positioned in airplanes (or by portable near-ground sensors, a more recent technology). When an airborne laser is pointed at a targeted area on the ground, the beam of light is reflected by the surface it encounters (Figure 4). A sensor records this reflected light to measure a range. When laser ranges are combined with position and orientation data generated from integrated GPS and Inertial Measurement Unit systems, scan angles, and calibration data, the result is a dense, detail-rich group of elevation points, called a “point cloud.”

Each point in the point cloud has three-dimensional spatial coordinates (latitude, longitude, and height) that correspond to a particular point on the Earth’s surface from which a laser pulse was reflected. The point clouds are used to generate other geospatial products, such as digital elevation models, tree canopy models, building models, and contours.
Airborne or aerial LiDAR technology provides very accurate and detailed 3-dimensional measurements of the ground, vegetation, and structures. LiDAR technology has developed rapidly in the past 15 years, and has become more affordable. The efficiency and accuracy of aerial LiDAR has made it possible to map large areas to a level of detail that in the past had only been accomplished with time-consuming and expensive on-the-ground survey crews.

In urban settings, LiDAR will capture the difference between “hard” built structures and diffuse surfaces, such as vegetation, by detecting a different pattern of the furthest return of the LiDAR beams. Buildings are composed of opaque skyward roof surfaces and vertical walls, making the interior of building structures invisible to laser scans as the beams can’t penetrate the structures. The rooftops (or ground) become the lowest visible surface at a certain x-y position, as illustrated in Figure 5. In contrast, trees and other vegetation are composed of branches and leaves that have multidimensional surfaces. With multiple passes of scanning from different angles, the point cloud captures not only the top surface of the tree crown, but also the surfaces inside and underneath the crown (also shown in Figure 5). Unlike buildings, point samples can exist underneath tree crowns. Applying computer algorithms, the point cloud can be classified to help visualize trees and other

Figure 4: Airborne LiDAR data scan.

Figure 5: LiDAR response to built versus vegetative surfaces.
credit: Qian-Yi Zhou, Stanford University
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vegetation around buildings and represent the 3D reality of urban settings. A range of vegetation metrics such as tree height, vegetation cover, crown dimensions and the vertical stratification of vegetation components may be possible to measure using LiDAR data.

Remotely sensed information in high-resolution raster forms (such as multi-spectral imagery or LiDAR products) can be processed into specific user-defined canopy cover, vegetation land cover, or vegetation type classifications. These classifications compliment and complete the more common parcel and infrastructure data of local government GIS platforms. Community leaders, officials and stakeholders can use such tools to assess and improve the health and wellness opportunities that metro nature can provide to people in their cities.

CONNECTING VEGETATION TO BENEFITS

The purpose of this section is to present opportunities to combine nature-based benefits knowledge with the technologies of remote sensing and GIS. The integrated spatial representations could then begin to reveal the location and degree of benefit provided by various landscape investments across a community, city or region – the analytic basis of a greenHEAL tool.

Table 2 is a concise representation of how to spatially recognize and model the degree of intersection of land use and vegetation for human benefit. The matrix is an overview of the critical vegetation features in the urban environment that relate to health and wellness. Each row calls out a specific set of benefits and the vegetation type or character that contributes to benefits. Looking horizontally across any row one finds a series of steps that suggest how digital data and tools could be used to discover the extent of vegetation (and benefit) across a city. The progression of boxes across each row describes a subset of health benefits, the vegetation component that generates such benefits, data sources, and data processing that would generate a map product. As one proceeds vertically down the matrix the vegetation feature becomes ever more specific to certain places in the city and landscape, garden, or park plantings. Vegetation scale or resolution also varies within the table; the top row is the analysis of canopy across an entire city, while the bottom row is the finely detailed expression of gardens or landscapes that one walks through or sees out a window.

The next section provides more detail about the data and processing, and describes in more detail how tree canopy information is derived, and how LiDAR might be used to detect ground level garden and understory conditions. Then a section describes the feasibility of this approach after surveying the geospatial resources that are available for several cities.
**Table 2: Comprehensive Modeling for Health Benefits Using Land Use and Vegetation Data.**

<table>
<thead>
<tr>
<th>Spatial Element</th>
<th>Health &amp; Well Being Benefit</th>
<th>Geo Description</th>
<th>Data</th>
<th>Processing</th>
<th>Product/Model Input</th>
</tr>
</thead>
<tbody>
<tr>
<td>Urban Forest Canopy</td>
<td>reduced particulates in air; positive affect &amp; mood; restorative effects (lower blood pressure &amp; heart rate)</td>
<td>citywide canopy cover classification (and impervious surface)</td>
<td>high resolution multispectral imagery (e.g. Quickbird, NAIP); LiDAR; orthophotos</td>
<td>pixel- or object-based classification of imagery</td>
<td>GIS layer, polygons of vegetation x land cover classification</td>
</tr>
<tr>
<td>UF Canopy Distribution</td>
<td>reduced cardiovascular and respiratory illness; better infant birth weight; reduced crime; food security</td>
<td>canopy density x residential zoning classifications</td>
<td>high res magery or photos (repurpose canopy analysis) x land use zoning</td>
<td>relational analysis or combined % canopy and buffering from residences for classification</td>
<td>GIS layer(s) with classification metric</td>
</tr>
<tr>
<td>Parks &amp; Open Spaces</td>
<td>active living; walking &amp; reduced depression; improved general health and life satisfaction; increased social cohesion &amp; social support</td>
<td>parcel locations of parks, open spaces, community gardens, critical areas</td>
<td>city/county parks parcel or inventory map</td>
<td>parcels + ½ mile buffer</td>
<td>parks and recreation GIS layer</td>
</tr>
<tr>
<td>Parks Vegetation</td>
<td>longer duration and more frequent moderate activity; reduced chronic disease; decreased elder mortality; youth activity</td>
<td>parks and open space vegetation classification and structure; edge conditions</td>
<td>vegetation data (repurpose canopy analysis) x city/county parks parcel or inventory polygon data</td>
<td>vegetation structure classification (canopy plus understory); buffer to ½ mile from parks boundary</td>
<td>GIS layer with parks/open space polygons; vegetation classification; edge buffer</td>
</tr>
<tr>
<td>Parks Elements</td>
<td>more frequent and diverse participation in active living; reduced ADHD</td>
<td>parks and recreation departments site inventories</td>
<td>classification of elements focusing on health activity or response (e.g. ball fields vs trails)</td>
<td></td>
<td>GIS layer with attribute table</td>
</tr>
<tr>
<td>Vacant Lot Conversions</td>
<td>reduced neighborhood crime; social cohesion</td>
<td>vacant lot locations</td>
<td>local government inventory; tax records</td>
<td>+/- status for each parcel</td>
<td>GIS parcel layer</td>
</tr>
</tbody>
</table>
# METRO NATURE HEALTH BENEFITS MAPPING

<table>
<thead>
<tr>
<th>Spatial Element</th>
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<th>Data</th>
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<th>Product/Model Input</th>
</tr>
</thead>
<tbody>
<tr>
<td>Green Roads &amp; Streets</td>
<td>reduced motorized vehicle crash incidence and severity; active living connectors; improved general mental health; stress recovery</td>
<td>street tree and green infrastructure locations relative to DOT urban road functional classification</td>
<td>street tree inventory &amp; other vegetation installations (e.g., green infrastructure); x local Public Works/DOT road classification map</td>
<td>combined classification based on vegetation and roads</td>
<td>GIS roads layer with vegetation attributes</td>
</tr>
<tr>
<td>Healing Places</td>
<td>faster and improved healing; reduced dementia and Alzheimer’s symptoms; reduced depression</td>
<td>specific land uses and built parcels that are medical facilities (including healing, care, and rehabilitation)</td>
<td>local government land use data and/or commercial properties records; occupancy rates; garden conditions using field delineation or remote sensing</td>
<td>healing place classification x vegetation classification x user/population density</td>
<td>GIS layer with parcel locations + attribute of vegetation x user density</td>
</tr>
<tr>
<td>Supportive Spaces</td>
<td>better school performance; less workplace illness; increased concentration/attention capacity</td>
<td>specific land uses and built parcels for work &amp; learning (including offices, campuses, schools)</td>
<td>local government zoning/land use data and/or commercial properties records; occupancy rates; garden conditions using field delineation or remote sensing</td>
<td>work/learning place locations x vegetation classification x user/population density</td>
<td>GIS layer with parcel locations + attribute of vegetation x user density</td>
</tr>
</tbody>
</table>
VEGETATION AND GEOSPATIAL ANALYSIS

Data Access, Processing and Products

As mentioned earlier, the urban landscape contains a heterogeneous mix of vegetation and land covers. High-resolution (<2.4m per pixel) remote sensing source data is needed to achieve accurate analysis and classifications. Medium resolution satellite data such as Landsat has a 30m per pixel resolution. Within a 30m pixel many critical features in the urban environment will not be distinguishable.

High resolution multi-spectral imagery in the U.S. is available from the National Agriculture Inventory Program (NAIP). NAIP imagery are digital orthophotographs and produced at 1m² pixel resolution. Other available high-resolution imagery includes Quickbird and RapidEye data, acquired from satellites and processed by commercial vendors. Quickbird’s resolution is 2.4m² per pixel, and RapidEye is 5m². The potential advantages of these images include a higher temporal resolution (they are re-acquired at frequent intervals) enabling updates with ongoing acquisitions. New NAIP datasets are available every 2 to 3 years.

LiDAR quality varied in the past, but today the typical standard is that the data will be recorded at >8 returns per m². Data contractors usually offer both a bare earth or last return product useful for creating digital terrain models, and also a first return product useful for canopy modeling. In addition to these products, a LiDAR acquisition includes an intensity return product and the raw LiDAR point cloud data. Both can be used in analysis, but require more sophisticated analytic processing capability.

LiDAR data is not yet available everywhere. Municipalities or regional entities contract and then manage local LiDAR data. For example in western WA State, the Puget Sound LiDAR Consortium makes all regional datasets that have been acquired with public funds available online or, for larger datasets, by direct file transfer onto personal devices or disks.

Data Translation and Features Classification

Both LiDAR and imagery require remote sensing analysis and processing to convert the rasterized data into useful information. At the most basic level, this work combines the knowledge of a team of scientists and analysts about the landscape contexts of the data location(s), a background and understanding about the research or analysis questions, and skill with the remote sensing tools, combined with adequate computer processing capacity, to glean meaningful information from the raw data.

Remote sensing science and methods continue to be refined, but “pixel-based” and “object-based” approaches have both been standardized. Pixel-based approaches develop classification algorithms or rule sets based on the
spectral, elevation, or intensity qualities in each pixel. Object-based approaches first aggregate the pixels into objects by “segmenting” rasters, then a classification rule set is developed. Pixel-based approaches were first developed to classify medium resolution imagery such as Landsat, and continue to be used with high-resolution data. As high-resolution data contains pixels that may be smaller than the landscape features being studied, object-based methods that begin by grouping these pixels into possible features are frequently used. In either case, the end products are GIS maps containing polygon vectors that have critical features classified, including tabular data that can be spatially related to other urban features or objects.

**Urban Tree Canopy Assessments**

Probably the most widely available vegetation classification approach at this time in U.S. cities is a tree inventory or canopy analysis.

A tree inventory is a widely used urban forestry planning and management tool. Location and attribute data for individual trees are entered into a dynamic database that, (optimistically) is periodically updated, particularly with tree care or management information. Inventories are often used by local government agencies to record and manage trees on public lands such as parks and transportation rights-of-way. Using species- and age-based canopy estimations for single trees, approximate estimations of vegetation classes may be possible.

Other approaches are used to assess canopy across all parcels – public and private – across a city. i-Tree Eco is a recognized approach for tree canopy estimation, and relies on on-the-ground measurements using sample plots. This requires that technicians (or trained volunteers in some instances) travel throughout a city to collect data. The process is complicated by access to private property, seasonal conditions (trees in leaf are best), and staff availability.

Mapping UTC using remote sensing and GIS has become a more affordable method for quantifying the existing urban forest and locations of potential canopy growth. Typically, cities elect to map UTC to establish a baseline for measuring change over time and to track progress toward community or planning-based canopy goals. Mapped results can be summarized across zoning, political, neighborhood (or other) boundaries, or other subzones of interest. Potential tree planting areas are also easily identified through the absence of existing tree cover.

Regarding the more technical aspects of UTC, an automated land cover methodology has been developed and applied by scientists to multiple cities in the U.S. Feature extraction is accomplished through the application of Object-Based Image Analysis (OBIA) techniques. The OBIA workflow consists of a rule-based expert system in which a series of image processing, segmentation, classification, and morphological algorithms are sequentially applied to spatial data.
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Most UTC analyses use a combination of LiDAR, digitized aerial orthophotography, or satellite imagery such as the National Agricultural Imagery Program (NAIP). These datasets are of high resolution, with both NAIP and LiDAR data having a resolution of 1m. Land cover features are extracted based on their spectral and textural properties in the imagery, their height attributes in the LiDAR, their shape, and their spatial relationship to one another. The typical product is a map or GIS layer displaying several land cover classes, for example: 1) tree canopy, 2) grass/shrub, 3) agricultural non-tree, and 4) other, often interpreted as impervious surfaces.

Compared to tree inventories, UTC assessments conducted using remote sensing generally do not provide specifics about individual tree species, health or maintenance needs, or obstructions to tree planting as certain urban features are not visible through remote imagery (such as overhead or underground utilities, preserved open space, or property owner choice). While these management considerations may be inferred from canopy cover extent, tree inventories remain necessary for estimating arborist workloads, potential threats, municipal liabilities, and specific tree planting opportunities.

The main advantages of UTC assessments are: (1) land cover is mapped for 100% of the study area; (2) remote sensing and GIS methods can incorporate many data sources that the city is likely to already possess (such as parcel boundaries, roads, water features, etc.); and (3) segmenting data according to management and planning boundaries (such as zoning types and neighborhoods), UTC extent can be associated with local policies and decisions. An advantage of remote sensing is that canopy assessment can be automated, with algorithms and command code being applied to analyze large, regional datasets.

LiDAR Explorations

As illustrated by Figure 1, there are metro nature conditions that are associated with human benefit that are of a much finer level of landscape design and detail within a city’s tree canopy. A significant portion of the project effort was focused on remote sensing and automation opportunities for first detecting, and then classifying, the sublayers of urban vegetation, that is, the understory layers of the urban forest.

We used part of the University of Washington as a case study. Figure 6 shows the study site. Appendix B provides a detailed description of the LiDAR dataset, and how the data were accessed. Fusion software was used to explore, visualize, and classify sub-canopy vegetation.

While this LiDAR acquisition included all of the City of Seattle and the analysis could have been applied to the entire city, the University of Washington campus was used as a case study for three reasons. First, the computational processing for LiDAR is demanding (particularly when using a desktop computer) and the study area size allowed a rapid, iterative assessment. Also, the campus offered a compellingly heterogeneous mix of
built structures and vegetation of varied heights and densities for study. Lastly, the project team is familiar with the on-the-ground conditions of the campus, so ground-truthing of the LiDAR analysis results could happen immediately.

Once the NAIP and LiDAR datasets were imported, pre-processed, and projected into a Fusion software project the case study area could be digitally visualized and vegetation could be classified. Figure 6 shows visual enhancement of the point cloud to enable on-screen inspection of vegetation layers and character from the LiDAR point cloud. Fusion software enables rotation of the point cloud to examine a setting from multiple perspectives, enabling the analyst to conceptualize additional modeling approaches.

In order to streamline processing of the vegetation data and to translate vegetation values to a vector layer that could be used in GIS, three parameters were computed. These parameters are arbitrary, but the rationale for their selection is related to the human health response literature. The first parameter was a vegetation coverage metric, mapping shrubs and trees, that is, any greenery above 1m in height. The second parameter is greenery below 20 feet, a height that might be useful to define and map vegetation below tree canopy in the study area. Lastly, the proportion of green vegetation between 5 and 10 feet, a height that is equivalent to the vegetation visible outside a first floor building window, or a tall shrub or shorter flowering tree height that would be visible to a pedestrian.

Figure 6: Aerial photograph of UW campus area used for metro nature LiDAR analysis, with point cloud display of subarea using color-enhanced height display.
Once computations were completed the results could be expressed as numbers and ratios, or visually inspected. Additional processing could combine attributes (such as vegetation height and proximity to building doors or windows). Decision points within such analysis would determine the grain or scale of vegetation display, with implications for computer processing times. Figure 7 and 8 show examples of this secondary processing.

The analysis was limited to a small area of Seattle. Ground-truthing determined that the computations did indeed capture the vegetation character of the test site. What would be the next steps in this analysis? The classification could now be applied to the entire Seattle metro area, or another urban area if remote sensing data were available.

HOW DO CITIES COMPARE?

The project team reviewed and inventoried the publicly available GIS datasets of 5 regionally representative U.S. cities to determine the availability of the important data sets for possible health benefits mapping and analysis.
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Seattle/King County, Atlanta, Minneapolis/Hennepin County, Baltimore/Baltimore County, and Denver. Both city and county governments were contacted in some locales as metro areas assemble and structure GIS layers differently. There was a high diversity in ability to access the data layers called out in Table 2, and it is likely that the cities would also vary in terms of data quality, precision, and shelf life. Here are some of the highlights across the cities. Additional details can be found in Appendix A.

Vegetation and Parks Layers

Baltimore and Minneapolis (using LiDAR), and Denver and Seattle (using imagery) each partnered with academic researchers and/or the USDA Forest Service to create their own urban vegetation, tree canopy cover, or land cover map classifications. Results differ somewhat based on each city's urban conservation goals. For example, Minneapolis analyzed urban tree canopy change by parcel (combining an urban forest and canopy distribution study with existing municipal parcel polygons) to track where and by whom improvements had been made toward its urban tree cover goals. In Baltimore, maps of canopy cover and impervious surface have been combined with street drain and stream layers to inform strategies for reducing sediment and runoff into Chesapeake Bay. In Sacramento, California, urban heat island, impervious surface, and urban tree canopy mapping has helped inform new parking lot tree shading ordinances that require 50% shading of paved areas in parking lots within 15 years after their development.

As seen in these examples, classified polygons of vegetation types and features can be added and related to other existing GIS data on locations of interest in the city. Some analysis of urban vegetation in relationship to zoning and parcels has been done in Baltimore, Minneapolis, and Seattle.

Presumably, vegetation classifications could be linked to parks polygons data. All five metropolitan areas have GIS polygon layers for parks. No cities had joined the locational information to vegetation information. Overall, the parks data varied widely. Some locations have listed attributes for parks, such as specific features, while others only assign a general “type” classification (such as ball fields versus trails). Minneapolis/Hennepin County and Denver have recorded basic parks elements and amenities. Atlanta simply records parks boundary polygons. Seattle parks elements can be found separately as data layers about community centers, swimming pools, and other constructed features. Only King County has a detailed database of GPS located parks elements.

Summary of Limitations

Generally, the quantity and quality of existing GIS layers in municipal GIS databases that could potentially relate to green spaces and to health and wellness varies greatly from city to city. Accessing location information for healing places and supportive spaces is less common and also varies widely. Atlanta and Baltimore offer publicly available institutional GIS data (for example, hospitals, schools). Seattle/King County GIS data for equivalent land uses could be found through WAGDA (the Washington State GIS data clearinghouse hosted by the University of
Washington Libraries) as discrete point files. Access to this information was not available from Denver. None of the city’s zoning or land use data were linked to vegetation.

Mapped locations of urban parks can be found in most cities, and some include the facilities or natural amenities within them. The locations of farmer’s markets or community gardens have often not been mapped. Municipal GIS databases include other critical areas, yet supportive services such as schools, hospitals, and rehabilitation centers or elderly facilities are often recorded only if publicly owned. Future effort to connect urban vegetation and green spaces with potential health and wellness benefits may require preparation of specific GIS layers for these locations of interest, to be derived from multiple GIS parcel records.

It may be necessary to aggregate data from sources outside of the municipal publicly available data or from numerous public databases. For example, Denver city public GIS service does not “re-distribute externally obtained” data. So, Denver offers no GIS information on the public schools from the Denver school district or hospital information from the Colorado Department of Public Health and Environment, or GIS information on libraries, after school programs, or elderly care, unless the city had created it. A comprehensive geospatial evaluation of health and wellness and urban vegetation for any city will likely include a review of the existence and quality of GIS layers describing the city’s parks, hospitals, schools, community gardens, and neighborhood health care facilities.

CONCLUSIONS & RECOMMENDATIONS

The proposed greenHEAL tool represents a major innovation in urban forestry benefits analysis. Map-based benefits display and analysis is not easy, but recent breakthroughs in remote sensing and geospatial data capture and processing now make this project concept feasible at reasonable cost. For instance, the analysis described here was completed on a budget of $9,500.

Figure 9 represents the most basic elements that need to be integrated to create the greenHEAL tool. The degree of nature-based health benefit is dependent upon knowledge of human presence, as
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indicated by land use and zoning within a city, and the location and character of nearby nature associated with various land uses. Many of the human health and well-being benefits are land-use based. There are distinct benefits associated with different land use types - such as residential, retail, commercial, and public institutions (for example schools). All of this happens at multiple scales – social (from individual to community), spatial (from single trees to large parks) and design detail (from the mere presence of trees to carefully designed small gardens). Mapping health benefits by land use and in relationship to canopy cover and other urban vegetation, further demonstrates the importance of urban forest planning and management for human functioning and health.

The evidence about metro nature and human health benefits has been compiled and is available at the Green Cities: Good Health web site. This project accomplished two other key tasks: a) exploration of remote sensing and geospatial tools that could specify vegetation location and character across a city, and 2) the extent to which local governments have geospatially recorded land uses and zoning.

Here are recommendations for next steps, based on lessons learned from this project. Other analytic models have developed iteratively starting with highest priority tasks, and incrementally adding new analysis modules or tools. The following list would help to prioritize future work on the greenHEAL project:

Health Benefits Impacts Evaluations and Prioritization

The health benefits literature is highly varied in method and reported benefits. Nonetheless, when reading the many studies it appears that there is differential benefit that is associated with different metro nature types or conditions. A first step would be to conduct an impact analysis. There could be two screens. One screen would be the number of people in a metro area that may be impacted by a vegetation condition. In other words what is the relative cumulative benefit of all residents having ½ mile access to parks in cities, versus having a certain degree of canopy cover? A second screen could be economic consequences, again considering the cumulative economic benefit or reduced costs. An example would be cost savings of hospital patients healing faster versus worker productivity with nearby nature contact.

Another aspect of impact assessment for health would be to search the evidence literature for more explicit vegetation classifications that are associated with the evidence of human health and well-being benefit. In other words, is health influenced by the mere presence/absence of vegetation, or is there a gradation of benefit associated with a gradation of vegetation?

Expand and Refine the greenHeal Benefits Analysis Model

This project was a very preliminary effort and proof of concept for greenHEAL. Initial outcomes were promising. LiDAR will become more commonly available. Assuming access to both detailed vegetation characterizations and land use GIS layers we think that it would be possible to conceptually structure an additive model for benefit
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assessment. The question is what computational algorithms are needed to determine the degree of benefit provided to residents and users of a defined urban space, such as a neighborhood? Another activity would be to work toward integrating geocoded data (probably using GIS) with benefits evidence economic valuation.

We have demonstrated a promising approach to the greenHEAL model. It is likely that use of remote sensing, particularly when using the spatial resolution of LiDAR data, can be combined with existing urban GIS vector data and other high resolution spectral imagery to classify urban vegetation conditions relative to locations where it offers measurable health benefits.

Other research aspects also persist. If the merge of health benefit, remote sensing classifications, and land use applications were to continue, what might be a standardized vegetation typing or classification that would enable more rapid and effective benefits estimation? Looking across the Green Cities Good Health benefits research database of >2,800 publications one sees that there is little consistency in how vegetation types or degree of presence is measured. A standardized scale would not only enable more rapid application of GIS analysis, but would also contribute to a more consistent and coherent research program about metro nature and human health benefits. To contribute to a more consistent and coherent research program about metro nature and human health benefits, it will be helpful to develop a useful scale that seeks to incorporate both our understanding of how we interact with urban vegetation in our cities and the resolution of new remote sensing data.

Streamline Analysis and Model Processing

Next steps would involve further evaluation of the feasibility of approaches for determining urban forest canopy, understory, and ground level vegetation. Would there be ways to collect or access high resolution datasets, particularly LiDAR, across more metro areas? In addition, the USDA Forest Service provided the software used in this project; it is command driven requiring a high level of expertise for use. Menu-driven, commercial software would make remote sensing data analysis easier and more efficient. Finally, additional exploration of how to classify smaller parcel or more detailed vegetation conditions is needed. For instance, considering hospital healing gardens, would it be possible to develop OBIA models that recognize the design conditions that produce benefit? Or would site inspections and data recording be more precise and/or more efficient than remote sensing for the finest grain of vegetation evaluation? Finally, more powerful computing resources would be needed to implement all of these recommendations.

Review Candidates for a Metro Region Case Study(s)

At the outset of the project it was expected that there are conventions for consistent GIS data layer construction and storage across cities. In the survey of cities this was not the case. Certain base layer information is fairly standard in most cities (such as zoning and transportation systems), but other land use and land cover conditions that are related to vegetation and health are inconsistently provided.
The next phase of this project could be to develop and implement a greenHEAL prototype in one city or several (such as places of small, medium, and large population). Cities could be screened and selected based on available base layer information, or information about vegetation classification, parks locations and features, and special land uses would have to be collected and processed.

**Closing**

Scientists call out that there is a "need for improvements in spatial, spectral, temporal and geometric resolutions for analysis of urban landscapes". New investigations are needed about “data and image fusion of different sensors, wavelength regions, spatial, spectral, and temporal resolutions, and the need for improved remote sensing systems . . . to facilitate more accurate measurements of characteristics integral to urban environments". Remote sensing has been used to research a growing range of urban environmental questions such as urban growth patterns, effects of impervious surfaces on temperature and hydrology, changes in biodiversity, carbon storage, and reuse of vacant lots.

This project was an exploration of the feasibility of merging existing evidence about human health and well being with the location and character of metro nature, including city trees and urban forests. The modeling is dependent on a fusion of improved resolution data. High-resolution data have been used with varied success to classify urban vegetation. We explored the potential for linking vegetation presence with the particular land uses and human populations that have been scientifically linked for human health and well being. To our knowledge this analysis and modeling has not been done by any other entity. While we did not complete a case study implementation of a model, we have built a framework and an understanding of the tools that can be applied to metro nature and health modeling. We will continue to pursue funding and collaborators to expand this effort.
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METRO NATURE HEALTH BENEFITS MAPPING


APPENDIX A: AVAILABLE VEGETATION MAPPING & GIS LAYERS FOR SELECTED U.S. CITIES

Atlanta

Urban Forest Canopy. No UFC maps online. The Atlanta “Tree Conservation Commission” leads tree canopy monitoring and advocacy.

Parks and Open Spaces. Parks polygons publicly available, downloadable online, likely digitally hand delineated. Little additional GIS information.

Parks Vegetation, Features, and Amenities. No details on features or amenities. No public parks map online.

Supportive Spaces Land Uses. Publicly available, downloadable point files for hospitals and schools with attribute table populated with information on the specific type of the facilities and GPS coordinates. Likely a combination of digitally hand delineated and field collected.

Baltimore, Baltimore County

Urban Forest Canopy And Canopy Distribution. Baltimore County completed an UTC study (by USFS and Jarlath O’Neill-Dunne). This assessment maps the county by percent cover and also height, using high resolution and medium resolution imagery and LiDAR height and intensity returns.

Parks and Open Spaces. Baltimore City offers downloadable point files of park locations. Points were field collected. Little additional GIS information.

Parks Vegetation. No details.

Parks Elements. No details on features or amenities. No public park maps.

Supportive Spaces Land Uses. Publicly available, downloadable point files for hospitals and schools with attribute table populated with information on the specific type of the facilities and GPS coordinates. Digitally hand delineated.
**Metro Nature Health Benefits Mapping**

**Denver**

**Urban Forest Canopy and Canopy Distribution.** Denver (collaborating with USFS and U.C. Davis researchers) produced a UTC and urban land cover classification using 2011 NAIP imagery (Denver lacks complete LiDAR coverage). The classifications were trees/shrubs (combined into UTC), irrigated non-woody vegetation, dry vegetation and bare soil, buildings, roads, other impervious surfaces, and water.

**Parks and Open Spaces.** Denver offers downloadable polygon files of park locations. The polygons were digitized from parcel data. Little additional GIS information beyond park “class” (Athletic Multiuse Complex, Community, Golf, Mountain, Neighborhood, Open Space, Pocket, Rec Center, Regional or Special Use).

**Parks Vegetation.** No specific details.

**Parks Elements.** Park amenities noted (trails, ball fields, etc.) as attributes. Denver offers digital and printed public park maps.

**Supportive Spaces Land Uses.** No publically available GIS information on hospitals, rehabilitation centers, hospices, schools, etc. was found.

**Minneapolis, Hennepin County**

**Urban Forest Canopy And Canopy Distribution.** In 2011, the University of Minnesota Remote Sensing and Geospatial Analysis Lab completed an UTC remote sensing study. This study included high resolution multispectral imagery and LiDAR. The study included an analysis of existing and possible UTC per parcel. In 2004 field crews collected 110 field plots and then using the Forest Service’s Urban Forest Effects model (UFORE, now i-Tree Eco) the urban forest was characterized and evaluated.

**Parks and Open Spaces.** GIS layers on parks and amenities available in both Minneapolis and Hennepin County.

**Parks Vegetation.** No details.

**Parks Elements.** Public maps are available for trails, bike paths, nature area, picnic areas, ball fields, dog parks, winter sports, etc.

**Supportive Spaces Land Uses.** Schools, hospitals, care centers likely could be parsed out of parcel data. Not readily available.
Seattle, King County

Urban Forest Canopy and Canopy Distribution. 2009 remote sensing assessment, using multispectral imagery from 2002 and 2007. The study included an analysis of existing building outlines, transportation, streets, and pavement areas, parcel data, and land use data.

Parks and Open Spaces. Requestable (and some downloadable), publicly available. Only health and well-being relevant attribute: “type”. No coordinates.

Parks Vegetation. No details.

Parks Elements. Seattle. From WAGDA, community center, swimming pools, can be found separately from “parks” attributes. King County. Everything. Ball fields to the locations of water spigots. Likely field collected. No coordinates online.

Supportive Spaces Land Uses. From WAGDA hospitals, community center, primary care facilities, etc. (and likely from City of Seattle) GIS data, schools, hospitals, care centers likely could be parsed out of parcel data. Not as readily available from city.
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APPENDIX B: FEASIBILITY OF LiDAR ANALYSIS FOR URBAN FOREST UNDERSTORY DETECTION

The following report details the explorations into use of LiDAR analysis for detection of urban forest understory vegetation. Such vegetation – such as parks, gardens, healing gardens, and other cultural landscapes – are associated with certain human health and well-being benefits, particularly as components of supportive spaces and healing places.

LiDAR, the source of remote sensing datasets, was introduced in an earlier section of the report. Raw LiDAR data is metaphorically a ‘cloud’ of digital, spatially defined points. Analytic, interpretive software is needed to analyze the data and provide the visualization of space and features. Fusion/LDV software was developed by scientists at the US Forest Service Pacific Northwest Research Station and the University of Washington to help researchers understand, explore, and analyze LiDAR data. LiDAR surveys commonly collect very large data sets, which initially could not be readily used with commercial GIS or image analysis tools. Fusion/LDV software has been designed to facilitate research with large LiDAR data sets from a variety of sources.

Fusion and the LDV (LiDAR data viewer) programs, together with a collection of task-specific command line programs form the analysis and visualization components of the system. Similar to the 2-dimensional display of GISs, Fusion displays a graphical display window and a control window. Fusion supports various data types including imagery, shapefiles, DTMs, canopy surface models, as well as LiDAR return data. The LDV provides a 3-dimensional visualization environment for review and measurements of the spatially-explicit subsets of the LiDAR data. The Command Line Programs allow specific analysis and the capability to make Fusion able to process larger LiDAR data sets.

The pages that follow describe the details of LiDAR analysis for urban understory vegetation using Fusion software.
Chris Vondrasek  
Independent Study Final Report  
“Urban Vegetation Analysis with LiDAR, A Case Study”

This report will outline a case study testing the possible use of LiDAR to measure urban vegetation within a context of buildings and open spaces. The proximity and spatial location both vertically and horizontally of urban vegetation relative to buildings, walkways, and other infrastructure may enhance or diminish to its possible influences on health and wellness. This case study used Fusion software and GIS to produce maps and spatial data. The study sought to demonstrate the potential for LiDAR analysis of vegetation in a complex urban setting. This report will outline data acquisition, the pre-processing steps for handling the LiDAR data, methods for the production in Fusion of grid metrics and outputs for use in GIS, and illustrate the graphic GIS outputs.

**The Data:** The LiDAR data was downloaded from the Puget Sound LiDAR Consortium (PSLC). The data was part of a LiDAR acquisition by King County in 2000, and is publicly available. The LiDAR data included both the vendor supplied bare earth DEM and the first return elevation model, as well as the raw LiDAR point cloud data. The spectral imagery was acquired from the University of Washington (UW) libraries via the WAGDA GIS Data site. The imagery was acquired as part of the 2011 National Agricultural Inventory Program (NAIP) Aerial Photography coverage. The imagery has a 1m per pixel resolution.

**The Study Area:** The study area was a section of the UW campus south of Red Square, north of the UW Medical Center, and approximately between 15\textsuperscript{th} Avenue NE and the Rainier Vista and the Drumheller Fountain. The area was chosen for its representative heterogeneity of buildings and open spaces interspersed with trees and shrubs of various heights.

**Data Acquisition:** It was necessary to acquire both NAIP imagery and the King County LiDAR data for the specific study area. The NAIP imagery was relatively simple, as the imagery can be downloaded in a compressed form by county and then clipped to the study area in GIS. The DEM and first return data products could be acquired in a similar way from the PSLC. However, the raw LiDAR files required a search to locate the study area within a county-wide index (a shapefile in GIS). I then downloaded the correct acquisition folder, and then worked through 25 possible sub-folders to find the right data (in Fusion).
**Pre-processing:** A key step in the preparation of the data to work in Fusion was to re-project the imagery to work with the LiDAR. This pre-processing parallels an critical diligence to re-project all newly created analysis products for the export from Fusion and into GIS in the later stages of the analysis process.

The raw LiDAR point cloud data arrives as an “ASCII” file, a digital file of numbers describing the x, y, and z coordinates, the return intensity, time or sequence of the lidar shot in seconds, the return number, the scan angle, the off-nadir angle, and the GPS type. These numbers must be imported and assigned meaning in Fusion to enable the software to work with them. Fusion will see and be able to place the points in space and allow analysis only after the software can translate the numeral information into LiDAR data. A similar, but slightly different processing also must occur with the bare earth ASCII file to create the digital terrain model, or DTM. The DTM is critical as many metrics are taken from the bare earth elevations.

The screen capture below shows the study area as well as a corner of a red box that indicates the sub-folder tile (#f3411), the bare earth DTM, and the NAIP imagery have all been correctly imported, pre-processed, loaded, and projected into a Fusion project. The two screen captures below this show the loaded project displayed, once colored according to height (with Suzzalo Library on the background edge in red), and the second colored using the imagery (and spun so the the view is to the south down the Rainier Vista with the Suzzalo profile and Red Square in the foreground). The black (particularly below the building roofs) is a result of no LiDAR points being returned from below the roof surface. The circle of Drumheller Fountain is a result of the LiDAR being absorbed by the water there.
Grid Metrics and Export Products: Grid Metrics is one of the ways that an analyst can create data and map products in a Fusion project. I chose this tool for the case study. Grid Metrics is useful for landscape scale analysis because based on parameters set by the analyst Fusion will create meaningful statistics in a continuous raster form that so that each cell has content. This content can be related or compared across a study area or landscape of interest.

To quote the Fusion manual: “GridMetrics computes a series of descriptive statistics for a LIDAR data set. Output is a raster (grid) represented in database form with each record corresponding to a single grid cell. ….. Cloudmetrics computes a single set of metrics for the entire data set. The default output from GridMetrics is an ASCII text file with comma separated values (CSV format). Field headings are included and the files are easily read into database and spreadsheet programs”.

I computed three parameters for the study area using Grid Metrics. These parameters hypothetically modeled urban vegetation in ways that related to potential health and wellness questions. First, I modeled a vegetation coverage metric, mapping where are there shrubs and trees, any greenery above 1m in the study area. Second, I modeled the proportion of greenery below 20 feet, a height that might be useful to define and map vegetation below the tree canopy in the study area. Lastly, I modeled the proportion of green vegetation between 5 and 10 feet, a height that might describe the vegetation visible outside a first floor building window, or describe a tall shrub, low flowering tree height for a pedestrian. This model included computations of green vegetation stratified from 0 to 5 feet, 5 to 10 feet, 10 to 15 feet, and 15 to 20 feet, but I chose to map and model just the 5 to 10 foot returns.

Each of these Grid Metrics computations or models involved a number of steps. I created a batch command for each, to be used through the DOS command box. Each batch command includes a executable command line, switches telling Fusion which returns to compute metrics on, a direction to find and use the bare earth DTM as a surface to normalize the LiDAR data and calculations to, parameters for the returns, directions to a file to spend the outputs to, and directions to the input LiDAR data file. As Fusion recognizes the only the executable command “Grdmetrics” to start the Grid Metrics computations, a specific file structure must be created for each discrete computation so that from the analyst's input to the
DOS command prompt box Fusion can find the correct version of Grid Metrics for the desired computation. The DOS command box below.

The "switches" segment of the batch command is a critical component of the Grid Metrics tool, because this is where the analyst can guide Fusion to compute descriptive statistics from specific returns or areas within the LiDAR point cloud. These "switches" included commands to compute coverage, to stratify returns (based on analyst defined parameters), or the limit returns to a designated height. The "parameters" part of the batch command is also a critical component as it defines the how the computation returns will be packaged, and possibly how useful they might be.

The Grid Metrics computations produces a spreadsheet type .CSV output, which also must be converted in Fusion into a grid ASCII form that can be exported to GIS. This “CSV2GRID” processing also requires creating a unique batch command in a way that allows Fusion to find the right executable “CSV2GRD” command (within the specific file structure) to convert the desired discrete computation into an ASCII form that ArcGIS will be able to make into a mappable raster form.

Outputs: After executing the CSV2GRD command I was left with ASCII files to bring back into ArcGIS for each of the three metrics. A raster in GIS has one value per pixel, so a key step in setting up the CSV2GRD command is finding the column in the output statistics in the .CSV file and returning that critical statistic to the ASCII file that will bring into ArcGIS the relevant information and make it available for the map and analysis. The stratified
computation produced a spreadsheet of dozens of columns for each different height stratification. For this study, I chose the proportion of returns at 5 to 10 feet. The file export steps for the coverage computation and the 'below 20 foot vegetation' computation were slightly simpler as the output .CSV files were less large.

Below (on the next pages) are 4 figures, a sampling of maps created from the descriptive or analytic statistics from the data, including examples of maps designed to communicate specific aspects of the vegetation features and their relationships to the neighboring built environment. The pixels in these maps correspond to specific descriptive statistics about the vegetation that may be compared across the study area.

**Conclusion:** This case study illustrates some of the potential for using LiDAR data in a complex urban setting for vegetation assessments, and for extracting information about specific metrics as well as descriptive statistics useful for analysis. I learned that the future use of LiDAR datasets on larger study areas will necessitate a keen attentiveness to creating cogent file structures. Also, a clear understanding of what one wants to understand about the urban vegetation structure will be key. The LiDAR data inputs can come from varied sources with clear or poor organization, and be of varying quality. The Fusion outputs can quickly become large and unwieldy.
This figure shows returns from vegetation 5 to 10 feet in elevation, and within 20m of the buildings. The buildings have been masked in grey, the 20m buffer line is purple, and the proportion of the returns range from .5 to 7.6%. The image layer appears partially transparent as a background layer. The GIS legend has been included also.
2) This figure shows the same vegetation strata (5 to 10 foot) but showing all returns in the range across the study site. This map depicts the presence of this strata of vegetation across all regions of the study area, many that are further from the buildings (which again are masked in grey). The darker green corresponds to a higher proportion of vegetation in this strata.
3) This figure shows the grid metrics for total vegetation coverage. The darkest blue corresponds to the most complete coverage from 1m to the top of the canopy. The lightest value (near white) has been set to map all places without vegetation above 1m, so the flat of Red Square and the flat lawn downhill from Drumheller Fountain have been classified similarly. The trees along Stevens Way or near Andersen Hall are classified dark blue, for example. A small capture of the aerial photograph has been placed for comparison.
4) This figure shows the below canopy vegetation layer (specifically from the ground to 20 feet). This metric might be used to discern areas where there is a more complete or complex vegetation understory, one possibly hidden from view below the tree canopy in normal aerial image analysis.