i-Tree Landscape Methods, Limitations and Uncertainties

i-Tree Landscape is an easy-to-use tool designed to:

a) Provide statistics on land cover, human populations and ecosystem services at the block group level up to the state level
b) Compare statistics among the various level of analysis
c) Prioritize areas (e.g., for tree planting) based on user-defined selections (e.g., poorest areas)
d) Produce outputs to aid in understanding urban forests and prioritizing management actions

This tool does not require any data inputs as all data are derived or input from various external sources. As some external sources have limitations regarding the accuracy of the data, this tool also has limitations and should be considered a first-order approximation of some results. To improve the accuracy of local data, users are encouraged to collect data on their local urban forest using i-Tree Eco and i-Tree Canopy. In the near future, this Landscape tool will connect with outputs from Eco and Canopy to help overcome these limitations.

i-Tree Landscape derives it data from NLCD tree, impervious and land cover data, U.S. Census data and national runs of ecosystem services from i-Tree Eco. These data are processed within various geographic boundaries:

- Census block groups
- Census places (e.g., cities, towns)
- Counties
- U.S. Congressional Districts
- States
- National Forest boundaries
- National Forest Ranger Districts
- Collaborative Forest Landscape Restoration (CFLR) project areas

More geographic boundaries will be added in the near future (e.g., watersheds, county subdivisions)

Data Layers

Basic data on cover types and populations statistics are derived from national sources and processed for each geographical unit.

NLCD tree cover – tree cover estimates are derived directly from 2011 National Land Cover Data (NLCD) or 2001 NLCD data in Puerto Rico (as 2011 data are not available). These data estimate percent tree cover using satellite data with a 30 meter resolution (www.mrlc.gov). The 2001 tree cover estimates are known to underestimate tree cover by an average of 9.7 percent, but the range of underestimation various by region and land cover class (Nowak and Greenfield 2010). It is believed, based on preliminary tests, that the 2011 tree cover maps also underestimate tree cover. Thus, the tree cover maps are likely conservative in estimating tree cover, and thus ecosystem services, which are derived from tree cover. To help overcome this believed underestimate of tree cover, high resolution tree cover maps are used where available.

High resolution tree and impervious cover – these data are typically sub-meter resolution data of tree and impervious surfaces. These maps typically have estimation errors of cover types at the pixel level around 5 percent or less and provide for better estimation and positioning of tree cover. These data are currently input into i-Tree Landscape for Baltimore, MD and Syracuse, NY, with more than 60 other areas to be input in the near future. As more high resolution maps become available, they will replace the NLCD tree and impervious cover maps and information.

NLCD impervious cover – like the tree cover estimates, these estimates are derived directly from 2011 National Land Cover Data (NLCD) or 2001 NLCD data in Puerto Rico. These data estimate percent impervious cover using satellite data with a 30 meter resolution (www.mrlc.gov). The 2001 impervious cover estimates are known to underestimate tree cover by an average of 1.4 percent (Nowak and Greenfield 2010). It is believed that the 2011 NLCD impervious data provide a reasonable estimate of impervious cover.

NLCD land cover – The 2011 NLCD provides a synoptic nationwide classification of land cover into 16 classes at a spatial resolution of 30 meters (www.mrlc.gov; US EPA 2015):

<u>Water</u>

11 Open Water - areas of open water, generally with less than 25% cover of vegetation or soil.

12 Perennial Ice/Snow - areas characterized by a perennial cover of ice and/or snow, generally greater than 25% of total cover.

<u>Developed</u>

21 Developed, Open Space - areas with a mixture of some constructed materials, but mostly vegetation in the form of lawn grasses. Impervious surfaces account for less than 20% of total cover. These areas most commonly include large-lot single-family housing units, parks, golf courses, and vegetation planted in developed settings for recreation, erosion control, or aesthetic purposes.

22 Developed, Low Intensity - areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 20% to 49% percent of total cover. These areas most commonly include single-family housing units.

23 Developed, Medium Intensity – areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 50% to 79% of the total cover. These areas most commonly include single-family housing units.

24 Developed High Intensity -highly developed areas where people reside or work in high numbers. Examples include apartment complexes, row houses and commercial/industrial. Impervious surfaces account for 80% to 100% of the total cover.

<u>Barren</u>

31 Barren Land (Rock/Sand/Clay) - areas of bedrock, desert pavement, scarps, talus, slides, volcanic material, glacial debris, sand dunes, strip mines, gravel pits and other accumulations of earthen material. Generally, vegetation accounts for less than 15% of total cover.

<u>Forest</u>

41 Deciduous Forest - areas dominated by trees generally greater than 5 meters tall, and greater than 20% of total vegetation cover. More than 75% of the tree species shed foliage simultaneously in response to seasonal change.

42 Evergreen Forest - areas dominated by trees generally greater than 5 meters tall, and greater than 20% of total vegetation cover. More than 75% of the tree species maintain their leaves all year. Canopy is never without green foliage.

43 Mixed Forest - areas dominated by trees generally greater than 5 meters tall, and greater than 20% of total vegetation cover. Neither deciduous nor evergreen species are greater than 75% of total tree cover.

Shrubland

51 Dwarf Scrub - Alaska only areas dominated by shrubs less than 20 centimeters tall with shrub canopy typically greater than 20% of total vegetation. This type is often co-associated with grasses, sedges, herbs, and non-vascular vegetation.

52 Shrub/Scrub - areas dominated by shrubs; less than 5 meters tall with shrub canopy typically greater than 20% of total vegetation. This class includes true shrubs, young trees in an early successional stage or trees stunted from environmental conditions.

Herbaceous

71 Grassland/Herbaceous - areas dominated by gramanoid or herbaceous vegetation, generally greater than 80% of total vegetation. These areas are not subject to intensive management such as tilling, but can be utilized for grazing.

72 Sedge/Herbaceous - Alaska only areas dominated by sedges and forbs, generally greater than 80% of total vegetation. This type can occur with significant other grasses or other grass like plants, and includes sedge tundra, and sedge tussock tundra.

73 Lichens - Alaska only areas dominated by fruticose or foliose lichens generally greater than 80% of total vegetation.

74 Moss - Alaska only areas dominated by mosses, generally greater than 80% of total vegetation.

Planted/Cultivated

81 Pasture/Hay – areas of grasses, legumes, or grass-legume mixtures planted for livestock grazing or the production of seed or hay crops, typically on a perennial cycle. Pasture/hay vegetation accounts for greater than 20% of total vegetation.

82 Cultivated Crops – areas used for the production of annual crops, such as corn, soybeans, vegetables, tobacco, and cotton, and also perennial woody crops such as orchards and vineyards. Crop vegetation accounts for greater than 20% of total vegetation. This class also includes all land being actively tilled.

Wetlands

90 Woody Wetlands - areas where forest or shrubland vegetation accounts for greater than 20% of vegetative cover and the soil or substrate is periodically saturated with or covered with water.

95 Emergent Herbaceous Wetlands - Areas where perennial herbaceous vegetation accounts for greater than 80% of vegetative cover and the soil or substrate is periodically saturated with or covered with water.

A formal accuracy assessment is underway for NLCD 2011 (US EPA 2015). The overall accuracy of earlier NLCD land cover classifications at the aggregated level reported in this indicator is 85 percent for NLCD 2001 and 84 percent for NLCD 2006. Overall accuracy at the level of the 16 underlying classifications is 79 percent for NLCD 2001 and 78 percent for NLCD 2006 (Wickham et al., 2013).

Census Data – U.S. population statistics are derived directly from the U.S. Census Bureau data (www.census.gov) and are believed to be without error. Census data are provided for each geographic unit for:

- Total population
- Median Age
- Percent minority
- Median income (from American Community Survey)
- Per capita income
- Percent poverty (from American Community Survey)
- Total housing Units
- Median year structure built (from American Community Survey)
- Median home value (from American Community Survey)
- Number of households
- Percent vacant households
- Number of households occupied by:
  - ✓ Family
    - Married couple
    - Other family
      - Male householder, no wife present
      - Female householder, no husband present
  - ✓ Non-family
    - Householder living alone
    - Householder not living alone
- Number of homes classified by tenure
  - ✓ Owned with mortgage or loan
  - ✓ No loan – free and clear
  - ✓ Rented
- Number of people classified by educational attainment for people over the age of 25 (from American Community Survey – only available at the block group level)
  - ✓ No school
  - ✓ Elementary school
  - ✓ High school
  - ✓ High school or GED

- ✓ Some college
- ✓ Undergraduate degree
- ✓ Graduate degree

Ecosystem Services

Based on the tree and impervious cover data, along with other local data, the following ecosystem services for trees in the area are assessed for the year 2010:

Carbon Storage and Annual Sequestration – these values are calculated from two separate sources depending upon location (NLCD land cover class).

Non-forest carbon: For non-forest NLCD classes, total carbon storage and net annual sequestration was estimated using value from urban forests (Nowak et al., 2013). Net annual sequestration is estimates of carbon accumulation from tree growth minus estimated carbon lost through decomposition due to tree mortality. Carbon storage was estimated based on the national average storage value of 7.69 kgC/m^2 tree cover (standard error (SE) = 1.36 kgC/m^2). Net sequestration was based on state estimates that varied based on length of growing season and averaged 0.226 kgC m^2 tree cover/yr (SE = 0.045 kgC m^2 tree cover/yr). State values varied from 0.430 kgC m^2tree cover/yr (Hawaii) to 0.135 kgC m^2 tree cover/yr (Wyoming) (Nowak and Greenfield 2010). These estimates per unit of tree cover are essential as these values were applied to the tree cover estimates (m^2) from the tree cover map to estimate total carbon (kg).

Forest carbon: For forested regions, total carbon storage and net annual sequestration were derived from U.S. Forest Service Forest Inventory and Analysis (FIA) data for each county[1]. Net annual sequestration was carbon accumulated annually between FIA remeasurements based on accumulation from tree growth and new trees minus carbon lost through tree mortality[2]. Total carbon storage and net sequestration per hectare of land was converted to total carbon storage and net sequestration per hectare of tree cover by dividing the carbon per hectare by percent tree cover in the forest land in the county. As tree cover on FIA land was not known, tree cover estimates from NLCD forest classes were used. In counties where tree cover in forest land was less than 10 percent (19 counties), tree cover was set to 10 percent to avoid inflating carbon density values per unit of cover due to low tree cover estimates. If no FIA carbon storage data existed for a county, but the county had tree cover with NLCD forest land, carbon storage density from the closest county were used. FIA carbon storage densities per m^2 of land area averaged 6.3 kgC/m^2; carbon storage density adjusted for tree cover equaled 9.8 kgC/m^2 tree cover. The average SE associated with these estimates is 1.3 kgC/m^2 tree cover.

[1] Special thanks to Jim Smith for extracting these county FIA data

[2] Note: sequestration in forest is based on field measurements of change including the influx of new trees and loss of existing trees; in non-forest areas, net sequestration is modeled based on tree growth of existing trees and estimated mortality based on tree condition over a one-year period; this estimate does not include new tree influx and only includes a partial loss of carbon from mortality due to decomposition (entire carbon from trees is not removed, only part of carbon lost to decomposition is removed).

As NLCD forest land (197 million ha) is much small than FIA forest land (264 million ha), the estimates derived for forest land in i-Tree Landscape will be lower than FIA estimates. For example, FIA forest land stores 16.7 billion metric tons of carbon in the conterminous U.S., but estimates from NLCD forest land using this procedure is 13.3 billion metric tons of carbon. FIA forest land and carbon estimates are about 30% more than derived using NLCD forest land due to the forest area differences (differences in definition and classification of forest land between FIA and NLCD). i-Tree Landscape uses NLCD for the classification of forest area.

Net sequestration per m^2 of tree cover was calculated in the same manner as for carbon storage. For net carbon sequestration, values for some counties are missing. If a county had a missing value, sequestration density values (kgC/m^2 tree cover/yr) from nearby counties in the same state were used. If the entire state had missing values, the county sequestration value was estimated based on converting the national FIA sequestration density value from all known counties to state values based on the ratio of state sequestration densities to national sequestration density for non-forest areas:

Forest sequestration density for state = national average forest density x (state non-forest sequestration density / national average non-forest density).

This procedure was used for net forest sequestration in many western states (AZ, CA, ID, MT, NM, NV, OR, UT, WA, WY). The average net sequestration value for forests was 0.14 kgC/m^2 tree cover/yr (average SE = 0.10 kgC/m^2 tree cover/yr) (https://www.itreetools.org/landscape/resources/Carbon_storage_and_seq_by_county_FIA.xlsx). This value is about 60 percent of the non-forest sequestration value. This difference is likely due to increased growth rates in urban areas (due to more open-grown nature of trees) and differences in means of calculating net sequestration (forest estimates remove all carbon from trees that die, but in urban estimates only a small portion are removed).

Value of carbon storage and sequestration is estimated at $139.33 / metric ton of carbon (Interagency Working Group, 2013).

Air Pollution Removal – air pollution removal and value estimates are based on procedures detailed in Nowak et al. (2014). This process used local tree cover, leaf area index, percent evergreen, weather, pollution and population data to estimate pollution removal (g/m^2 tree cover) and values ($/$m^2$ tree cover) in urban and rural areas for each county. These values are applied to the m^2 of tree cover to determine total removal and values related to carbon monoxide (CO), nitrogen dioxide (NO_2), ozone (O_3), particulate matter less than 2.5 microns (PM2.5), particulate matter between 2.5 and 10 microns (PM10*) and sulfur dioxide (SO_2). Values estimates are based on local health impacts estimated using the U.S. EPA BenMAP model for each county (based on local population data) for all pollutants except for CO and PM10*, which use externality values ($/t) to estimate pollutant removal value.

Estimates of pollution removal varied by county (https://www.itreetools.org/landscape/resources/Landscape_air_pollutant_removal_ranges.xlsx).

Average county removal rates are used, but have a potential maximum and minimum value (Table 2) that illustrates a potential range. The minimum and maximum values on average are about 57 percent of the mean value. Average differences from the mean varied from a low of 30 percent for NO_2 to a high of 106 percent for PM2.5. The maximum and minimum values are likely unreasonable values as they assume a maximum or minimum removal rate for every hour of the year. No maximum or minimum values are estimated for CO.

Hydrologic Effects – Estimates of evaporation, transpiration, precipitation interception and avoided runoff for each county in the conterminous United States in 2010 were developed using i-Tree Eco Model and local leaf area indices and weather data. Methods are detailed in Hirabayashi (2015), Hirabayashi and Endreny (2015) and Hirabayashi and Nowak (2015). The bound of error on these estimates is unknown.

Prioritization

To determine the best locations to plant or protect trees, tree and impervious cover data in conjunction with U.S. Census data can be used to create an index to highlight priority areas among the selected geographic units. With these index values, the higher the index value, the higher the priority of the area for tree planting or protection. The index is developed by weighting the layers that are selected by the user along with the associated weights. Up to three layers can be selected with each layer weight between 0 to 100, such that the sum of the layer weights must equal 100. Currently, the layers that can be selected to produce the index are:

- Population density (all) – higher density is weighted higher
- Population density (minority populations) – higher density is weighted higher
- Percent population below poverty line – higher percent is weighted higher
- Tree cover per capita – lower values are weighted higher
- Tree stocking level (percent of pervious land occupied by tree cover) – lower values are weighted higher

As geographic areas differ in size, all index inputs are either in percentages or standardized per unit area or person. Some layers have lower values leading higher index values, while other have higher values leading to higher index values. Each non-percentage layer was standardized on a scale of 0 to 1 with 1 representing the geographic area with the highest value in relation to priority (e.g., areas with highest population density, lowest stocking density or lowest tree cover per capita were standardized to a rating of 1).

Standardized values for population density (PD) were calculated as:

$$PD = (n - m) / r$$

Where PD is the value (0-1), n is the value for the geographic area (population / km2), m is the minimum value for all geographic areas, and r is the range of values among all selected areas (maximum value – minimum value).

Standardized value for percent population below poverty line (BPL) was calculated as:

BPL = percent population below poverty line / 100

Standardized value for tree cover per capita (TPC) was calculated as:

$$TPC = 1 - [(n - m) / r]$$

Where TPC is the value (0-1), n is the value for the census block (m^2/capita), m is the minimum value for all census blocks, and r is the range of values among all census blocks (maximum value – minimum value).

Standardized value for tree stocking (TS) was calculated as:

$$TS = [1 - (t/(t+g)]$$

Where TS is the value (0-1), t is percent tree cover, and g is percent grass cover.

Individual scores were combined based on the following formula to produce an overall priority index (PI) value, where the user selects the index layer and its weight:

PI = (index 1 * weight 1) + (index 2 * weight 2) + (index 3 * weight 3)

The final index was standardized to yield values between 0 (lowest priority) and 100 (highest priority).

A default index is given based on PD, TS, and TPC, where the default index = (PD * 40) + (TS * 30) + (TPC * 30). This index is a type of "environmental equity" index with areas with higher human population density and lower tree cover tending to get a higher index value.

Summary

Information from data layers are direct estimates from a primary source. Ecosystem services and value estimates are derived as secondary estimates from the data layers and other sources. The primary data layer used is tree cover, thus limitations of this layer will affect ecosystem service estimates.

Data	Summary	Estimate
NLCD tree cover	10% average underestimate per area in 2001; unknown but likely underestimate in 2011	Conservative estimate

High resolution tree cover	Likely within a few percent	OK- Errors are believed to compensate
NLCD impervious cover	Possible minor (~1%) underestimate of impervious cover	OK
NLCD land cover	Estimated 80% accuracy, but formal accuracy tests are underway	OK - Errors are believed to compensate
Census Data	Accurate – based on census	OK
Carbon storage	National average C density from urban areas are used for non-forest areas (relative SE of 17.7%); County C density from FIA data are used for forest areas (relative SE of 13.3%)	Conservative estimate if using NLCD tree cover
Carbon sequestration	State average C sequestration density from urban areas used for non-forest areas (relative SE of 19.9%); Estimated county C sequestration density from FIA data (not all counties had values) used for forest areas (relative SE of 71.4%)	Conservative estimate if using NLCD tree cover
Air Pollution removal	County pollution removal estimates; max and min values are on average about 57% of the mean	Conservative estimate if using NLCD tree cover
Hydrology	Estimates based on local weather and leaf area indices. Bound of error is unknown	Conservative estimate if using NLCD tree cover

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Table 2. Average of county mean, minimum (min) and maximum (max) pollution removal rates (g/m^2 of tree cover/yr)

	CO			NO2			O3			PM10*			PM2.5			SO2	
min	mean	max	min	mean	max	min	mean	max	min	mean	max	min	mean	max	min	mean	max
0.108	0.108	0.108	0.351	0.535	0.669	2.233	5.129	6.773	0.609	1.560	2.436	0.033	0.243	0.547	0.201	0.336	0.526