The Science and Future of i-Tree

David J. Nowak
USDA Forest Service
Syracuse, NY

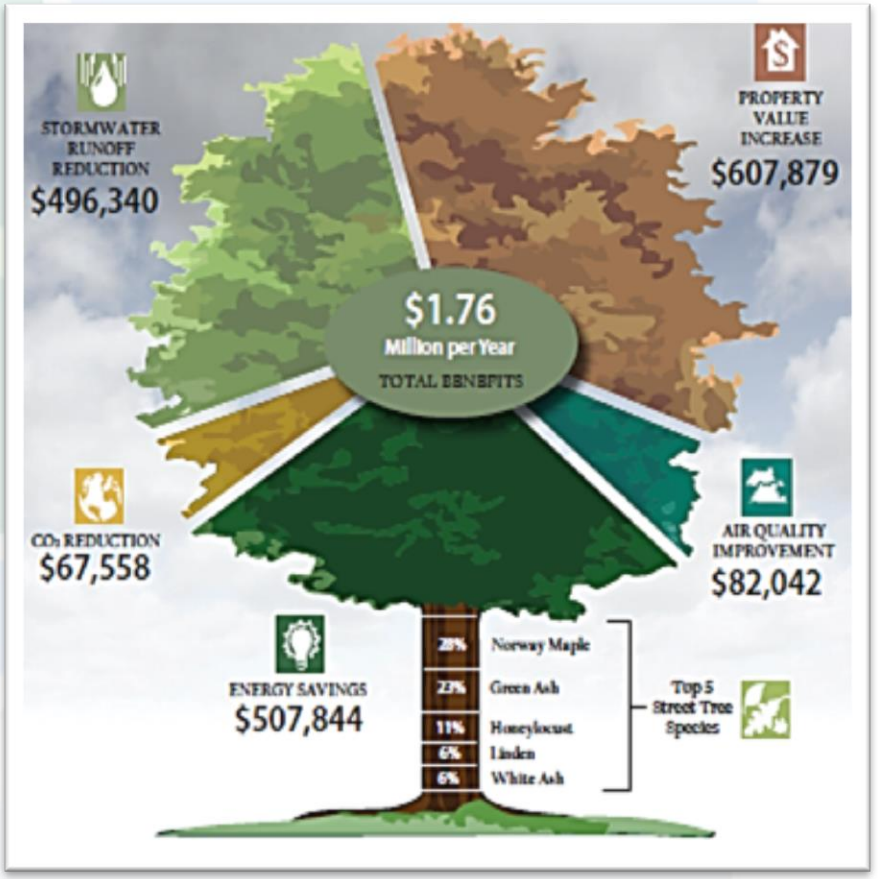
Overview

- Introduction and Science (20 minutes)
- Q&A (10 minutes)
- i-Tree Update (15 minutes)
- Q&A (10 minutes)

What is i-Tree?

www.itreetools.org

A collaborative public-private partnership and suite of tools that provides:



- Assessment of current and future forest structure and benefits
- Optimal tree planting and design
- Sustainable and resilient forest management
- Public engagement in stewardship

What is i-Tree?

www.itreetools.org

Purpose: Guide management decisions with best available science and local data

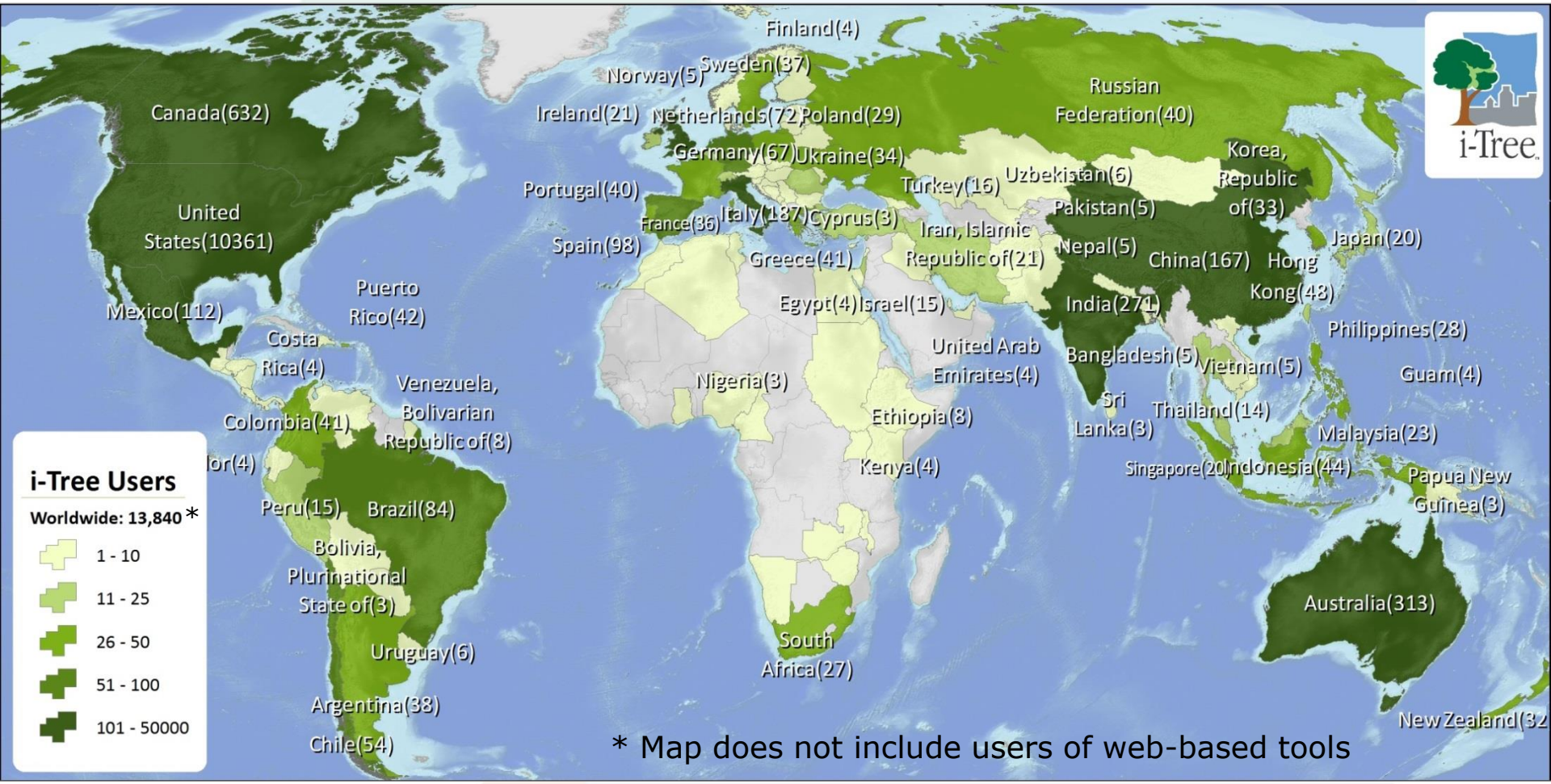
- Designed to easily engage managers and general population
- Data are being used in innovative ways to make a difference:
- Management plans, advocacy, education, tree planting goals, etc.

What is i-Tree?

www.itreetools.org

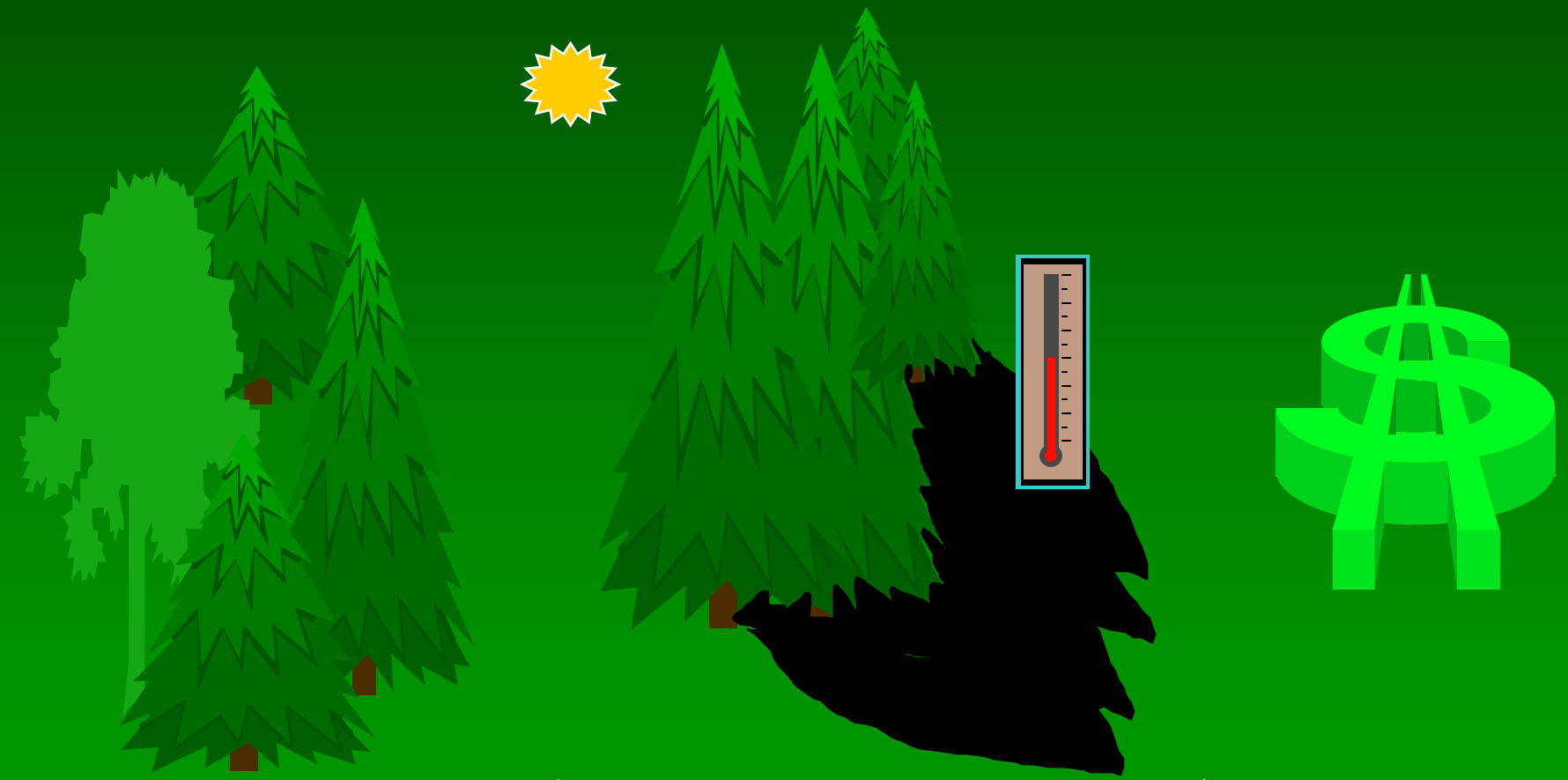
A series of FREE tools to quantify ecosystem services and values from trees (free support also)

The program is global.



Over 36,000 users in 120 countries

Model Framework



Structure ⇨ Function ⇨ Value

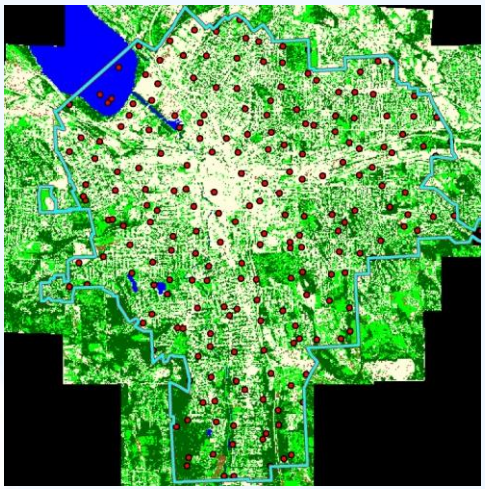
Population model

- Good at estimating population totals
- More discrepancy when predicting individuals
  - Issue: predictive equations – tendency to mean
- Ease of data collection vs more variables or instrumentation
- Uses local environmental data (weather, pollution)
  - Area average
  - Local variation – NEXRAD, Fused data, Temp model
- Structural variables are most important

Assessing Urban Forest Structure

Aerial

Ground-based



Science - Structure

- Structure is critical starting point
- Standard sampling statistics
  - Inventory vs. sample
- Standard error on measured variables
  - No. trees, dbh, species counts, height
- Standard error – derived variables
  - Sampling error, not error of estimation
  - Leaf area, leaf biomass, functions

Structural References

- Nowak, D.J. 1991. Urban Forest Development and Structure: Analysis of Oakland, California. PhD dissertation. University of California, Berkeley. 232p.
- Nowak, D.J. 1993. Historical vegetation change in Oakland and its implications for urban forest management. J. Arboric. 19(5):313-319.
- Nowak, D.J. 1994. Urban forest structure: the state of Chicago's urban forest. In: McPherson, E.G, D.J. Nowak and R.A. Rowntree. Chicago's Urban Forest Ecosystem: Results of the Chicago Urban Forest Climate Project. USDA Forest Service General Technical Report NE-186. pp. 3-18; 140-164.
- Nowak, D.J. 1996. Estimating leaf area and leaf biomass of open-grown urban deciduous trees. For. Sci. 42(4):504-507.
- Nowak, D.J., R.A. Rowntree, E.G. McPherson, S.M. Sisinni, E. Kerkmann and J.C. Stevens. 1996. Measuring and analyzing urban tree cover. Lands. Urban Plann. 36:49-57.
- Nowak, D.J., J. Pasek, R. Sequeira, D.E. Crane, and V. Mastro. 2001. Potential effect of Anoplophora glabripennis (Coleoptera: Cerambycidae) on urban trees in the United States. J. Econon. Entomol. 94(1):116-122.
- Nowak, D.J., D.E. Crane, J.C. Stevens, and M. Ibarra. 2002. Brooklyn's Urban Forest. USDA Forest Service Gen. Tech. Rep. NE-290. 107p.
- Myeong, S., D.J. Nowak, P.F. Hopkins, and R.H. Brock. 2003. Urban cover mapping using digital, high-resolution aerial imagery. Urban Ecosystems. 5:243-256

Structural References (cont.)

- Peper, P.J. and E.G. McPherson. 2003. Evaluation of four methods for estimating leaf area of isolated trees. Urban Forestry and Urban Greening 2:19-29
- Nowak, D.J., M. Kurodo, and D.E. Crane. 2004. Urban tree mortality rates and tree population projections in Baltimore, Maryland, USA. Urban Forestry and Urban Greening. 2(3):139-147.
- Nowak, D.J., R.E. Hoehn, D.E. Crane, J.C. Stevens, J.T. Walton, and J. Bond. 2008. A ground-based method of assessing urban forest structure and ecosystem services. Arboric. Urb. For. 34(6): 347-358
- Walton, J.T., D.J. Nowak, and E.J. Greenfield. 2008. Assessing urban forest canopy cover using airborne or satellite imagery. Arboric. Urb. For. 34(6): 334-340
- Nowak, D.J., J.T. Walton, J.C. Stevens, D.E. Crane, and R.E. Hoehn. 2008. Effect of plot and sample size on timing and precision of urban forest assessments. Arboric. Urb. For. 34(6): 386-390
- Woodall, C.W. D.J. Nowak, G.C. Likens, and J.A. Westfall. 2010. Assessing the potential for urban trees to facilitate forest tree migration in the eastern United States. Forest Ecology and Management. 259:1447-1454.
- Nowak, D.J. and E. Greenfield. 2010. Evaluating the National Land Cover Database tree canopy and impervious cover estimates across the conterminous United States: A comparison with photo-interpreted estimates. Environmental Management. 46: 378-390.
- Nowak, D.J. and E.J. Greenfield. 2012. Tree and impervious cover change in U.S. cities. Urban Forestry and Urban Greening. 11:21-30.

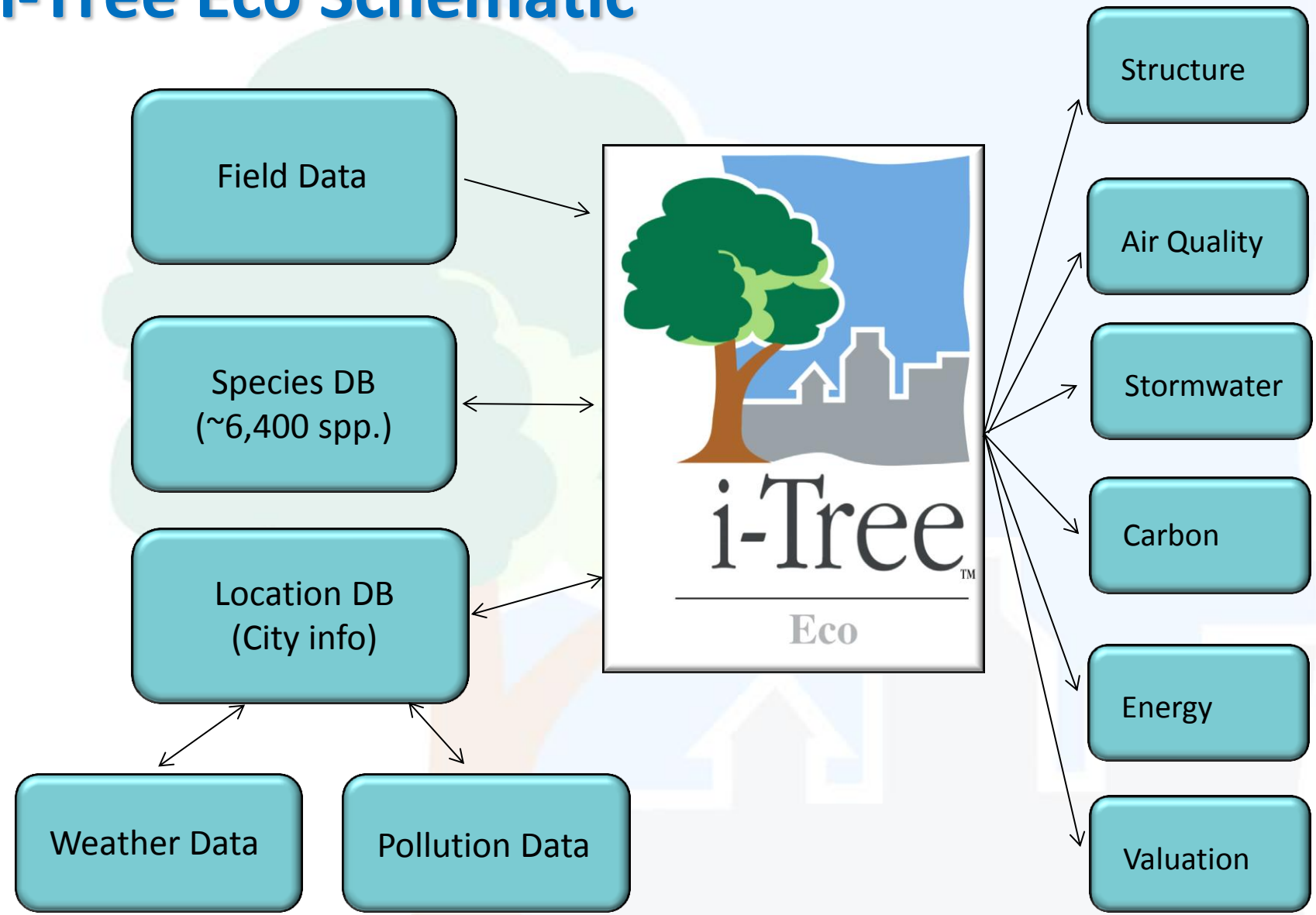
Structural References (cont.)

- Nowak, D.J. and E.J. Greenfield. 2012. Tree and impervious cover in the United States. Landscape and Urban Planning. 107: 21– 30
- Nowak, D.J. 2012. Contrasting natural regeneration and tree planting in 14 North American cities. Urban Forestry and Urban Greening. 11: 374– 382
- Nowak, D.J., R.E. Hoehn, A.R. Bodine, E.J. Greenfield, J. O'Neil-Dunne. 2013. Urban Forest Structure, Ecosystem Services and Change in Syracuse, NY. Urban Ecosystems. DOI 10.1007/s11252-0
- Nock, C.A., A. Paquette, M. Follett, D.J. Nowak and C. Messier. 2013. Effects of urbanization on tree species functional diversity in eastern North America. Ecosystems 16: 1487-1497

i-Tree Calculated Benefits

- Air quality improvement
- Water flow and water quality improvement
- Greenhouse gas reduction
- Building energy use conservation
- Oxygen production
- Health benefits
- Cooler air temperatures
- UV radiation reduction
- Pollen
- Wildlife habitat
- Insect biodiversity
- Products: timber, food, fiber, ethanol

i-Tree Eco Schematic



Function Process

- Determine link between structure and functions
- Develop or use algorithms that predict functions based on structural estimates
- Quantify impact of function
- Peer-reviewed papers on methods
- Additional detailed model documentation of methods is on i-Tree web site
- Outputs tested against measured variables

Air Pollution Removal

- Inputs: Daily leaf area; hourly weather and pollution data
- Methods: dry deposition modeling (gas exchange)
- Certainty: hourly rates in line with measured rates
  - Max and min values given (limitation – drought)

- Nowak, D.J. 1994. Air pollution removal by Chicago's urban forest. In: McPherson, E.G, D.J. Nowak and R.A. Rowntree. Chicago's Urban Forest Ecosystem: Results of the Chicago Urban Forest Climate Project. USDA Forest Service General Technical Report NE-186. pp. 63-81.
- Nowak, D.J., P.J. McHale, M. Ibarra, D. Crane, J. Stevens, and C. Luley. 1998. Modeling the effects of urban vegetation on air pollution. In: Gryning, S.E. and N. Chaumerliac (eds.) Air Pollution Modeling and Its Application XII. Plenum Press, New York. pp. 399-407.
- Nowak, D.J., K.L. Civerolo, S.T. Rao, G. Sistla, C.J. Luley, and D.E. Crane. 2000. A modeling study of the impact of urban trees on ozone. Atmos. Environ. 34:1610-1613.
- Nowak, D.J., D.E. Crane, J.C. Stevens, and M. Ibarra. 2002. Brooklyn's Urban Forest. USDA Forest Service Gen. Tech. Rep. NE-290. 107p.
- Wu, Z. J.R. McBride, D.J. Nowak, J. Yang, and S. Cheng. 2003. Effects of urban forests on air pollution in Hefei City. Journal of Chinese Urban Forestry. 1: 39-43
- Nowak, D.J., D.E. Crane and J.C. Stevens. 2006. Air pollution removal by urban trees and shrubs in the United States. Urban Forestry and Urban Greening. 4:115-123

Pollution References (cont.)

- Escobedo, F.J., J.E. Wagner, D.J. Nowak, C.L. De la Maza, M. Rodriguez, and D.E. Crane. 2008. Analyzing the cost-effectiveness of Santiago de Chile's policy of using urban forests to improve air quality. J. Environ. Manage. 86: 148-157
- Escobedo, F. and D.J. Nowak. 2009. Spatial heterogeneity and air pollution removal by an urban forest. Landscape and Urban Planning. 90:102-110
- Morani, A., D. Nowak, S. Hirabayashi, and C. Calfapietra. 2011. Tree Planting Locations in New York City to Enhance Pollution Removal Relative to Human Populations. Environmental Pollution. 159: 1040-1047
- Hirabayashi, S., C. Kroll, and D. Nowak. 2011. Component-based development and sensitivity analyses of an air pollutant dry deposition model. Environmental Modeling and Software. 26:804-816.
- Hirabayashi, S., C.N. Kroll and D.J. Nowak. 2012. Development of a distributed air pollutant dry deposition modeling framework. Environmental Pollution. 171: 9-17.
- Nowak, D.J., S. Hirabayshi, A. Bodine and R. Hoehn. 2013. Modeled PM2.5 removal by trees in ten U.S. cities and associated health effects. Environmental Pollution. 178: 395-402.
- Cabaraban, M.T., C. Kroll, S. Hirabayashi, and D. Nowak. 2013. Modeling of air pollutant removal by dry deposition to urban trees using a WRF/CMAQ/i-Tree Eco coupled system. Environmental Pollution. 176: 123-133
- Nowak, D.J. S. Hirabayashi, E. Ellis and E.J. Greenfield. 2014. Tree and forest effects on air quality and human health in the United States. Environmental Pollution 193:119-129
- Morani, A., D. Nowak, S. Hirabayashi, G. Guidolotti, M. Medori, V. Muzzini, S. Fares, G. Scarascia Mugnozza, C. Calfapietra. 2014. Comparing modeled ozone deposition with field measurements in a periurban Mediterranean forest. Environmental Pollution 195: 202-209

Carbon storage and sequestration

- Inputs: Species, dbh, condition, location, crown competition
- Methods: Allometic biomass equations; growth based on condition, length of growing season, crown competition (adding new equations and wood density conversions)
- Certainty: standardized rates in line with FIA rates
  - SE based on sampling error

- Nowak, D.J. 1991. Urban Forest Development and Structure: Analysis of Oakland, California. PhD dissertation. University of California, Berkeley. 232p.
- Nowak, D.J. 1993. Atmospheric carbon reduction by urban trees. J. Environ. Manage. 37(3):207-217.

Carbon references (cont.)

- Nowak, D.J. 1994. Atmospheric carbon dioxide reduction by Chicago's urban forest. In: McPherson, E.G, D.J. Nowak and R.A. Rowntree. Chicago's Urban Forest Ecosystem: Results of the Chicago Urban Forest Climate Project. USDA Forest Service General Technical Report NE-186. pp. 83-94.
- Nowak, D.J. and D.E. Crane. 2002. Carbon storage and sequestration by urban trees in the USA. Environ. Poll. 116(3):381-389.
- Nowak, D.J., J.C. Stevens, S.M. Sisinni, and C.J. Luley. 2002. Effects of urban tree management and species selection on atmospheric carbon dioxide. J. Arboric. 28(3):113-122.
- Pouyat, R.V., I.D. Yesilonis, and D. Nowak. 2006. Carbon storage by urban soils in the United States. J. Environ. Quality. 35:1566-1575.
- Heath, L.S., J.E. Smith, K.E. Skog, D.J. Nowak, and C.W. Woodall. 2011. Managed forest carbon estimates for the U.S. Greenhouse Gas Inventory, 1990-2008. Journal of Forestry. April/May: 167-173
- Nowak, D.J., E.J. Greenfield, R. Hoehn, and E. LaPoint. 2013. Carbon storage and sequestration by trees in urban and community areas of the United States. Environmental Pollution. 178: 229-236.

Oxygen production

- Inputs: Species, dbh, condition, location, crown competition
- Methods: conversion of carbon sequestration rates
- Certainty: same as carbon
  - SE based on sampling error
- Nowak, D.J., R.H. Hoehn, and D.E. Crane. 2007. Oxygen production by urban trees in the United States. Arboriculture and Urban Forestry. 33(3):220-226

VOC emissions

- Inputs: Daily leaf biomass by species; hourly weather data
- Methods: EPA BEIS modeling procedures
- Certainty: standardized rates in line with BEIS rates

- Geron, C.D.; Guenther, A.B.; Pierce, T.E. 1994. An improved model for estimating emissions of volatile organic compounds from forests in the eastern United States. Journal of Geophysical Research. 99(D6): 12,773-12,791.
- Guenther, A. 1997. Seasonal and spatial variation in natural volatile organic compound emissions. Ecological Applications. 7(1): 34-45.
- Guenther, A.; Hewitt, C.N.; Erickson, D.; Fall, R.; Geron, C.; Graedel, T.; Harley, P.; Klinger, L.; Lerdau, M.; McKay, W.A.; Pierce, T.; Scholes, B.; Steinbrecher, R.; Tallamraju, R.; Taylor, J.; Zimmerman, P. 1995. A global model of natural volatile organic compound emissions. Journal of Geophysical Research. 100 (D5): 8873-8892.
- National Oceanic and Atmospheric Administration / U.S. Environmental Protection Agency. 2008. Biogenic Emissions Inventory System (BEIS) Modeling. http://www.epa.gov/asmdnerl/biogen.html.

Building Energy Conservation

- Inputs: Tree height, condition, distance and direction from building, geographic location
- Methods: Micropas and Shadow Pattern Simulator modeling
- Certainty: unknown

- McPherson, E.G. and J.R. Simpson. 1999. Carbon dioxide reduction through urban forestry: Guidelines for professional and volunteer tree planters. Gen. Tech. Rep. PSW-171. Albany, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station. 237 p.

Hydrology – water flow and runoff

- Inputs: Daily leaf area; hourly weather data; DEM
- Methods: physically based TOPMODEL design
- Certainty: model calibrated against stream flow data

- Wang, J., T.A. Endreny, and D.J. Nowak. 2008. Mechanistic simulation of urban tree effects in an urban water balance model. Journal of American Water Resource Association. 44(1):75-85.
- Yang, Y., T. Endreny, and D. Nowak. 2011. iTree-Hydro: snow budget and stormwater pollutant updates for the urban forest hydrology model. Journal of the American Water Resources Association. 47(6):1211-1218.
- Yang, Y. TA. Endreny, D.J. Nowak. In press. Simulating the effect of flow path roughness to examine how green infrastructure restores urban runoff timing and magnitude. Urban Forestry & Urban Greening
- Yang, Y., T. Endreny, and D. Nowak. In Press. Simulating the two-peak hydrograph of urban runoff with parallel application of fast and slow advection-diffusion hydrograph models. Hydrology and Earth System Sciences

Modules in Development

Air temperature effects

- Yang Y., T.A. Endreny, and D J. Nowak. 2013. A physically-based local air temperature model. Journal of Geophysics Research-Atmospheres. 118: 1–15
- Heisler, G., A. Ellis, D. Nowak and I. Yesilonis. In press. Modeling and picturing land-cover influences on air-temperature in and near Baltimore, MD. Theoretical and Applied Climatology

Wildlife habitat

- Lerman, S.B, K.H. Nislow, D.J. Nowak, S. DeStefano, D.I. King and D.T. Jones-Farrand. 2014. Using urban forest assessment tools to model bird habitat potential. Landscape and Urban Planning. 122:29-40.

UV radiation reduction

- Na, H.R., G.M. Heisler, D.J. Nowak, and R.H. Grant. 2014. Modeling of urban trees' effects on reducing human exposure to UV radiation in Seoul, Korea. Urban Forestry and Urban Greening 13:785-792

Value Processes

Structure – CTLA process

- Nowak, D.J. 1993. Compensatory value of an urban forest: an application of the tree-value formula. J. Arboric. 19(3):173-177.
- Nowak, D.J., D.E. Crane, and J.F. Dwyer. 2002. Compensatory value of urban trees in the United States. J. Arboric. 28(4):194-199.

Pollution removal – BenMAP or externality

- U.S. Environmental Protection Agency (US EPA). 2012. Environmental Benefits Mapping and Analysis Program (BenMAP). http://www.epa.gov/air/benmap/
- Nowak, D.J., S. Hirabayshi, A. Bodine and R. Hoehn. 2013. Modeled PM2.5 removal by trees in ten U.S. cities and associated health effects. Environmental Pollution. 178: 395-402.
- Nowak, D.J. S. Hirabayashi, E. Ellis and E.J. Greenfield. 2014. Tree and forest effects on air quality and human health in the United States. Environmental Pollution 193:119-129

Carbon – social cost of carbon

- Interagency Working Group on Social Cost of Carbon, United States Government. 2013. Technical Support Document: Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 12866 (3% discount rate)

Energy – average state utility costs

Value Processes

- Runoff reduction – average treatment costs
  - McPherson et al., Peper et al. and Vargas et al. 16 Regional Community Tree Guides. PSW General Technical Reports.
- Oxygen
  - Nowak, D.J., R.H. Hoehn, and D.E. Crane. 2007. Oxygen production by urban trees in the United States. Arboriculture and Urban Forestry. 33(3):220-226
- VOC emissions – need to convert to secondary pollutants

Model Differences

- Field data required
  - i-Tree Eco and Design

- Average effects per unit tree cover
  - State (carbon) or county (pollution removal) averages
  - i-Tree Canopy
  - i-Tree Landscape
    - Entry level program
    - Will be coupled to i-Tree Eco

Questions?

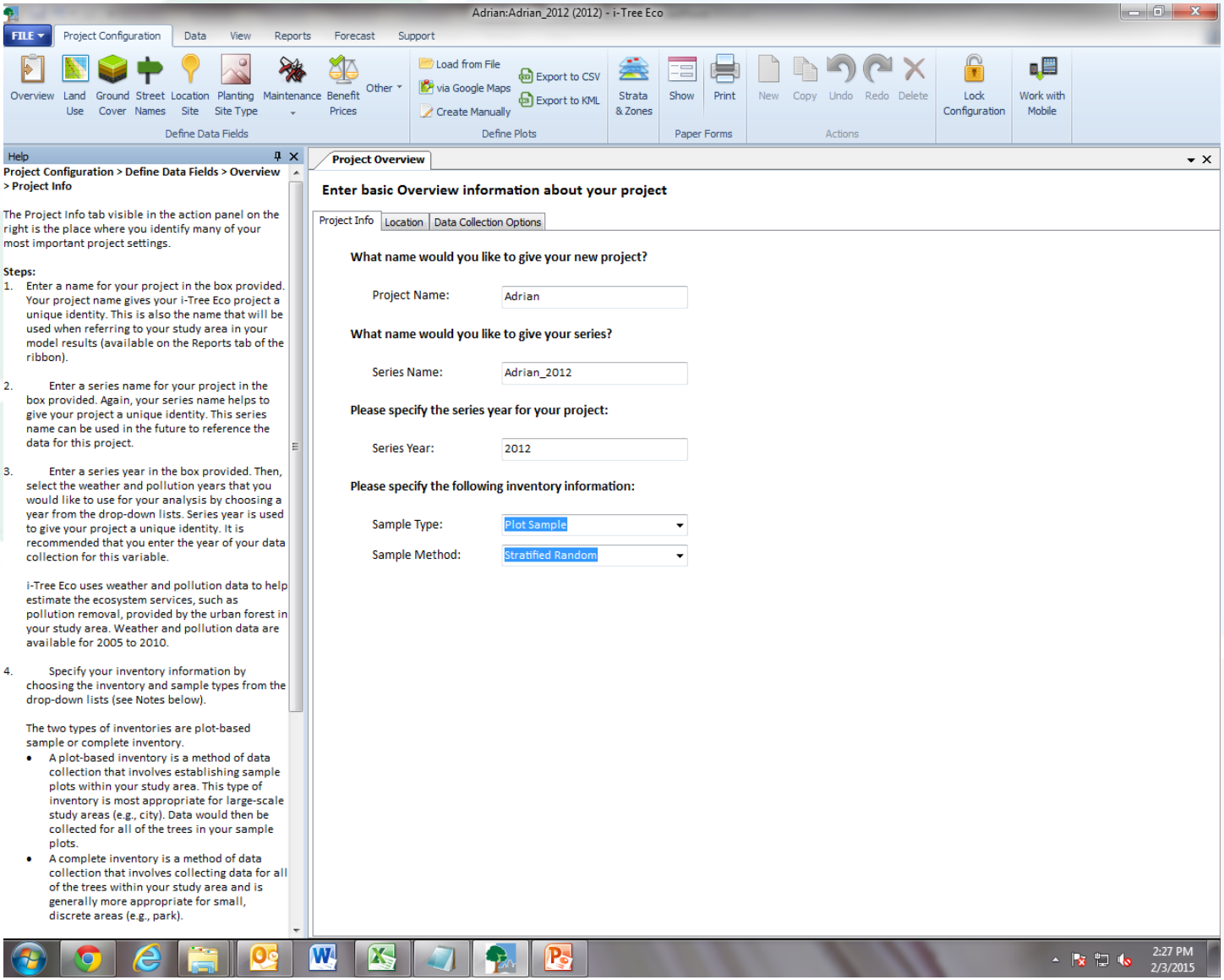
i-Tree Update

- Urban FIA
- 2015 release
  - i-Tree Eco
    - Forecast
  - i-Tree Landscape
- Upcoming features

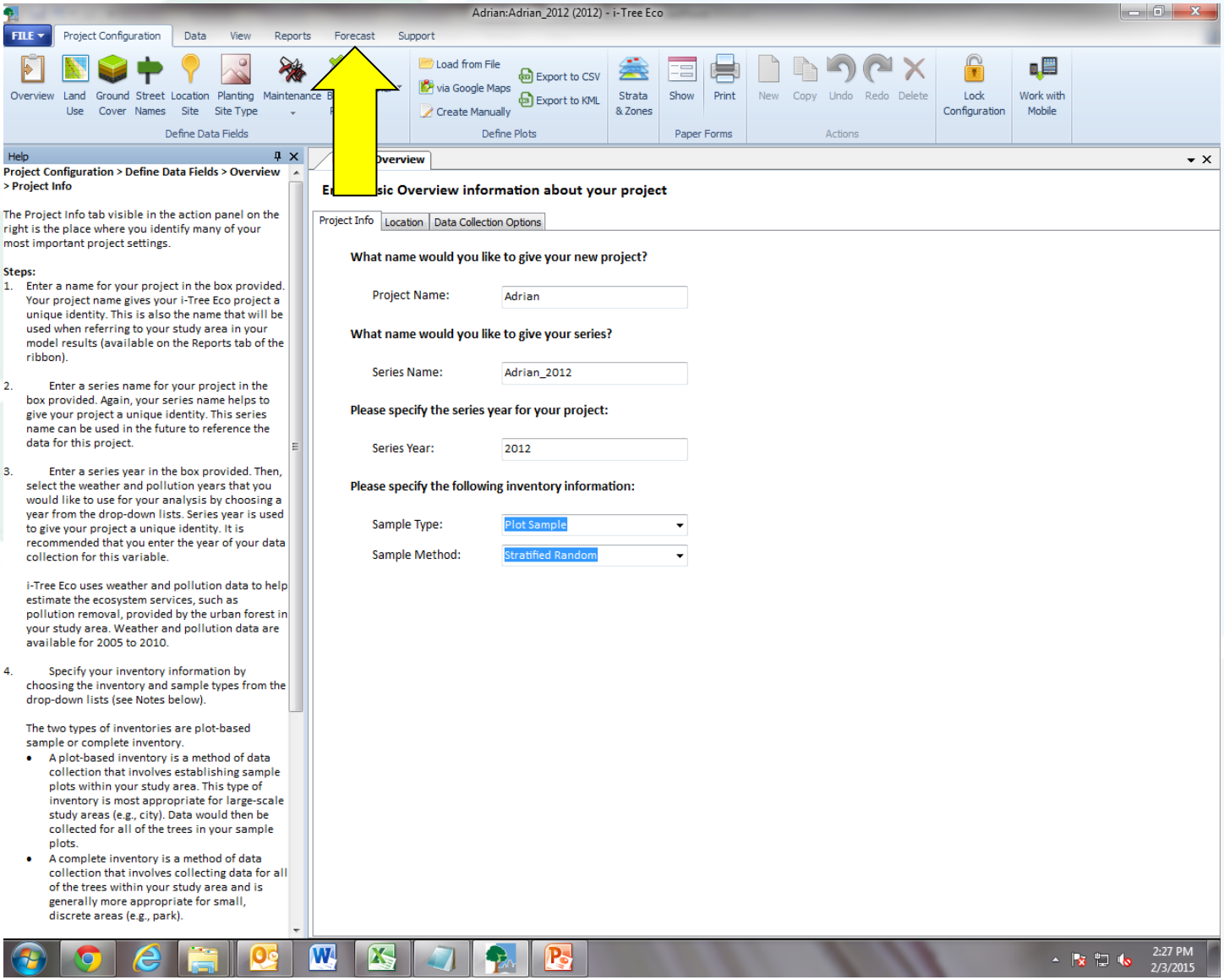
Urban FIA (Forest Inventory and Analysis)

- Pilot testing protocols since the late 1990's
  - State assessments through the early 2000s
- 2014 Farm Bill – Urban FIA
  - Shift to metro areas
- Panel system; 200 1/6 acre plot with microplots
- Selection based on partnership
  - 2015 – Austin*, Baltimore
  - 2016 – Houston*, Madison, Milwaukee, St. Louis, Providence, Des Moines
- Goal – top 100 metro areas

Eco Updates (2015)



Eco Updates (2015)

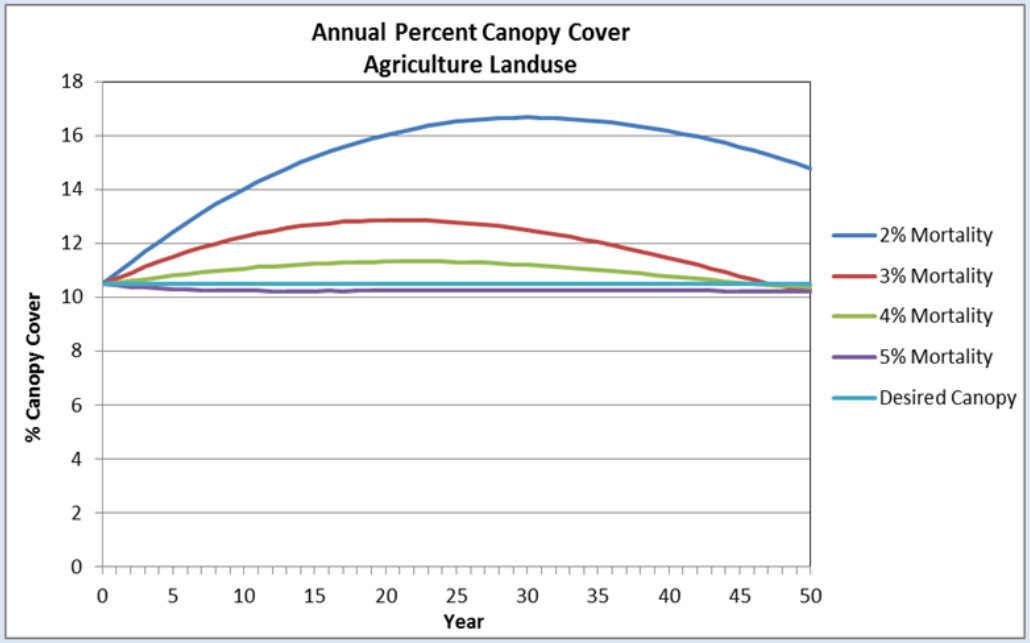


Simulating forest growth

Forecast

Project Variables | Management Scenarios | Canned Scenarios | Model Outputs | **Help**

Total | **By Land Use**



Agriculture Land Use - Desired Canopy = 10.5 %

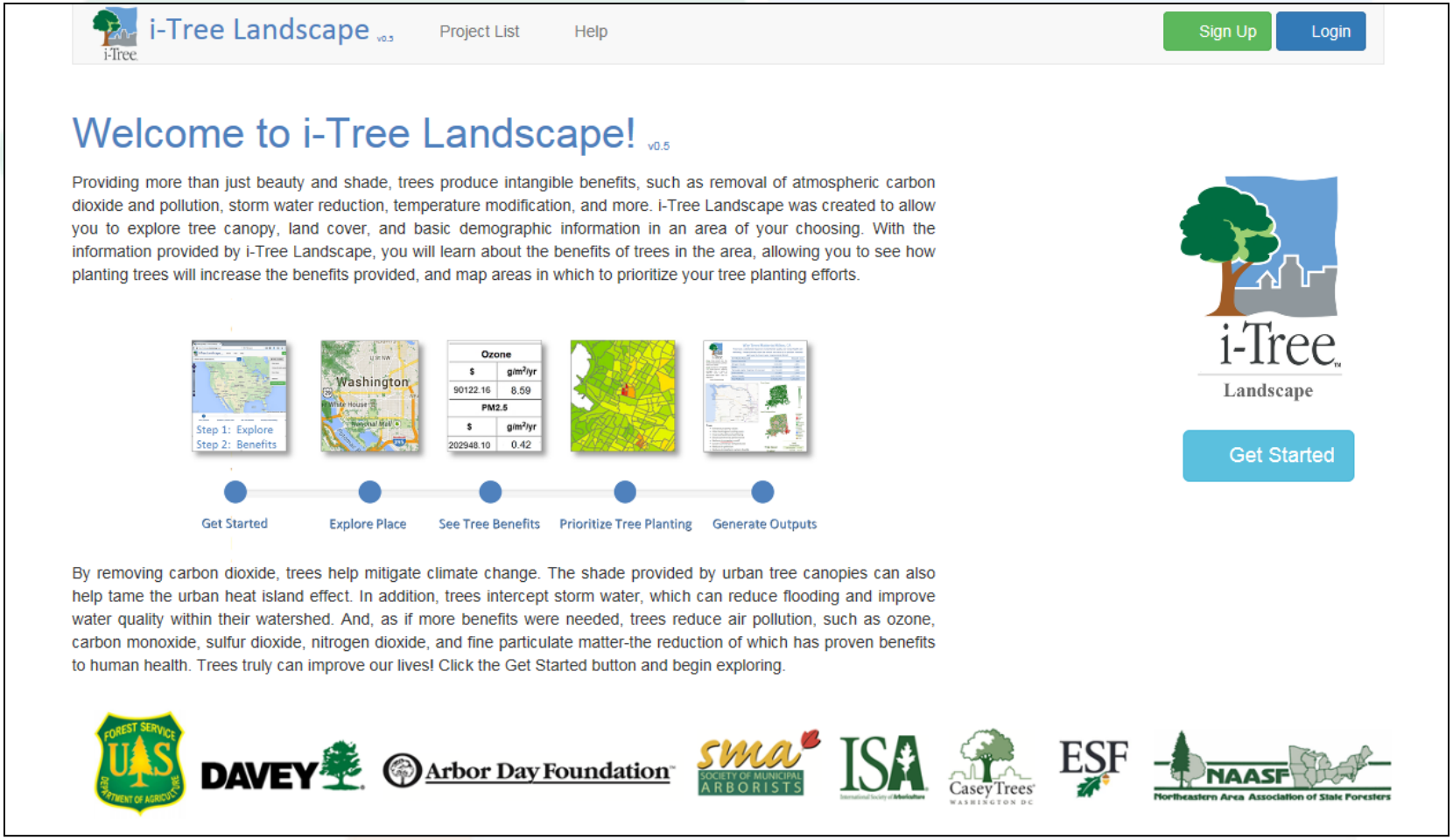
Years	Mortality (%)	Output Canopy (%)	Trees Planted
50	2	14.78	0
50	3	10.25	63,000
50	4	10.37	201,000
50	5	10.2	340,000

Table | Graph

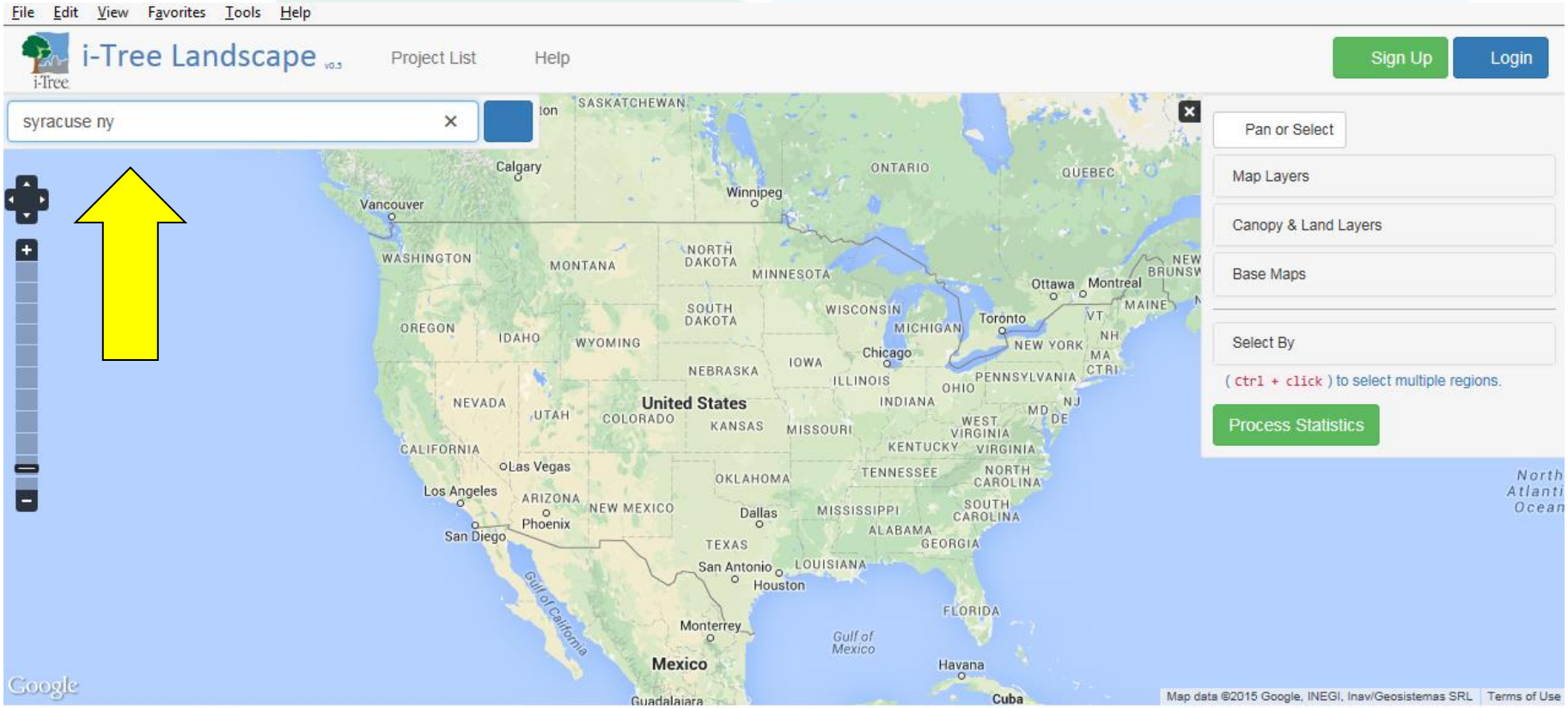
Next Land Use

i-Tree Landscape

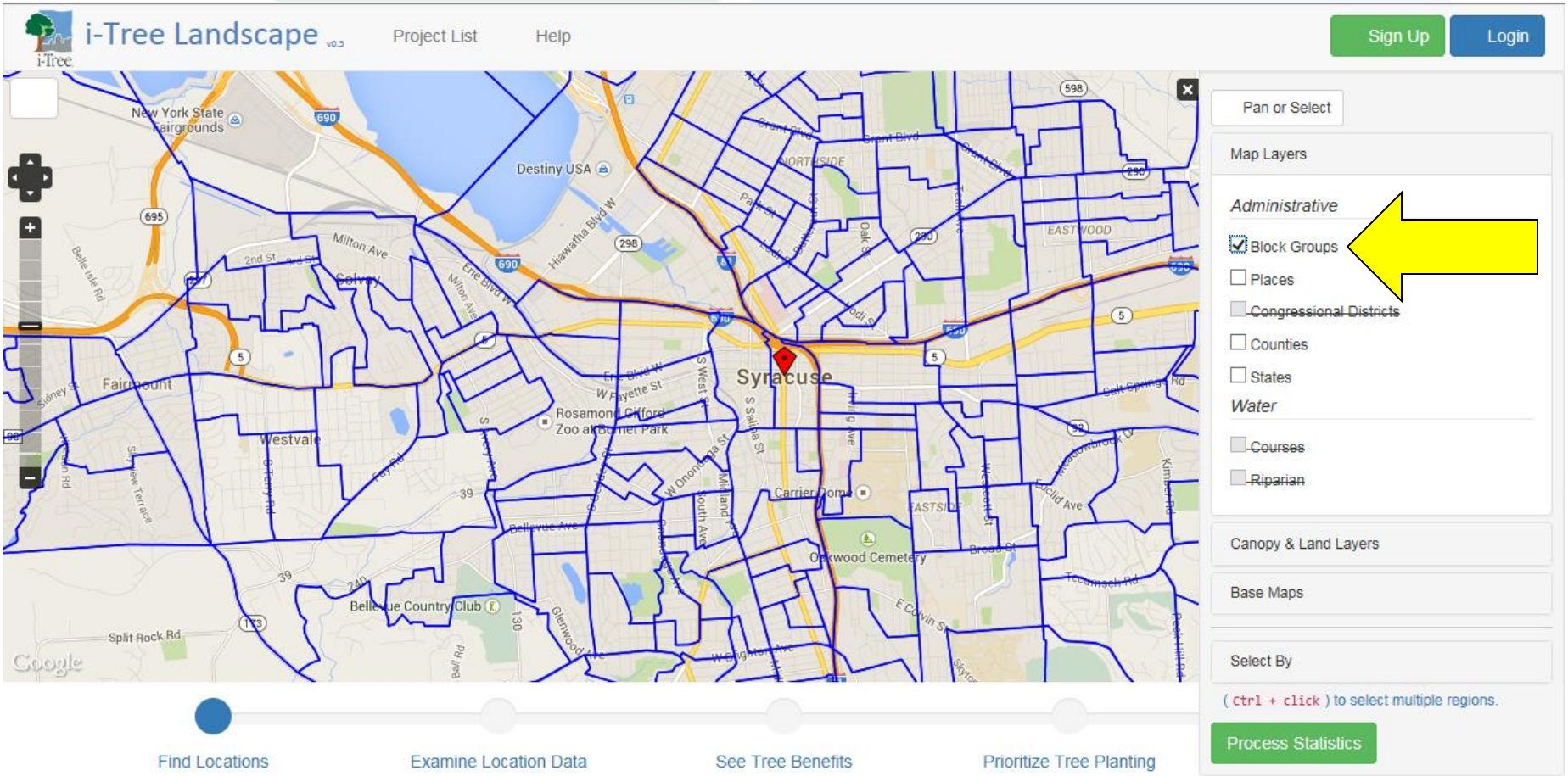
- National NLCD land cover, tree cover and impervious cover
- Local UTC tree and impervious cover (where available)



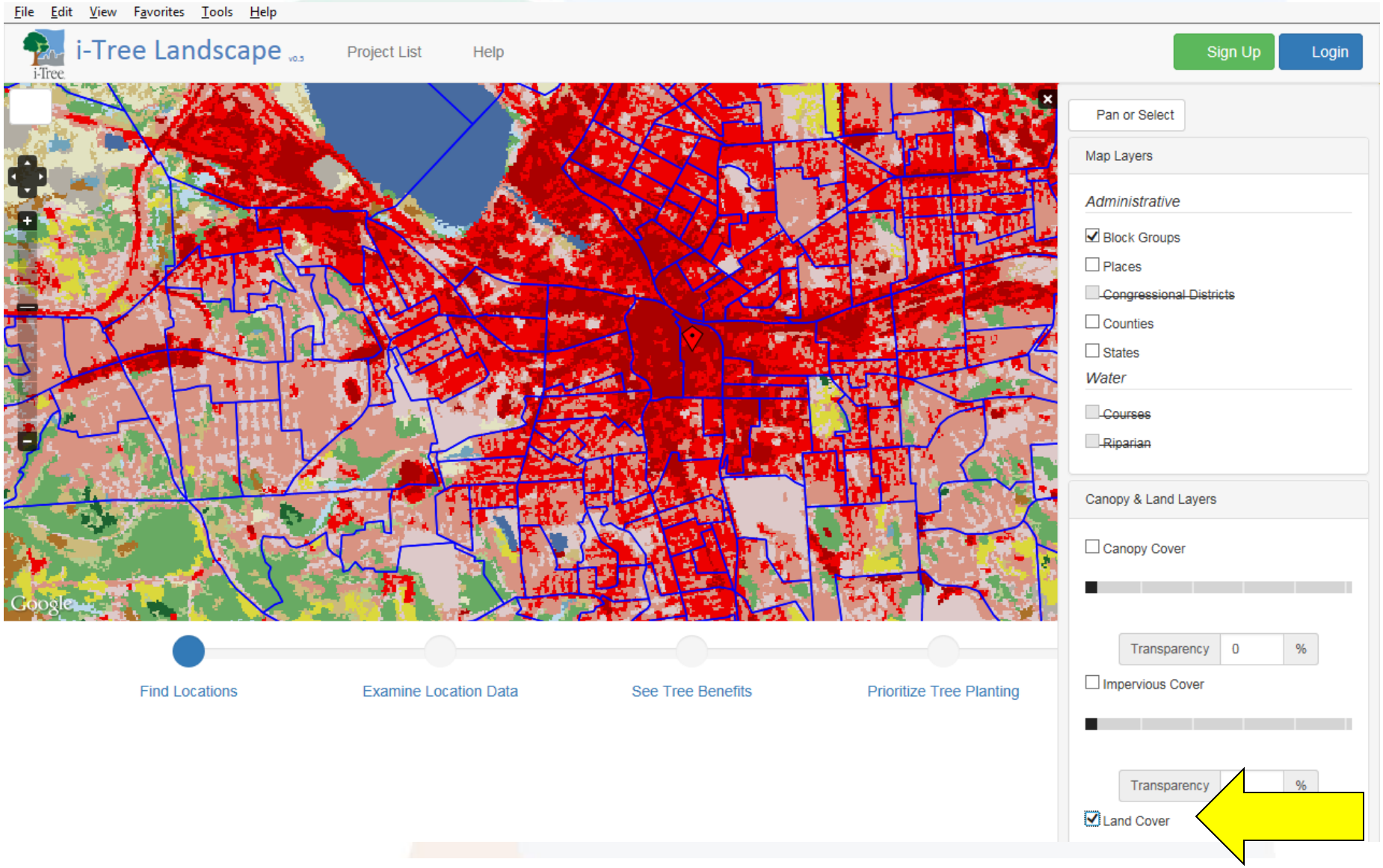
i-Tree Landscape – Select Area



i-Tree Landscape – Select Analysis Groups

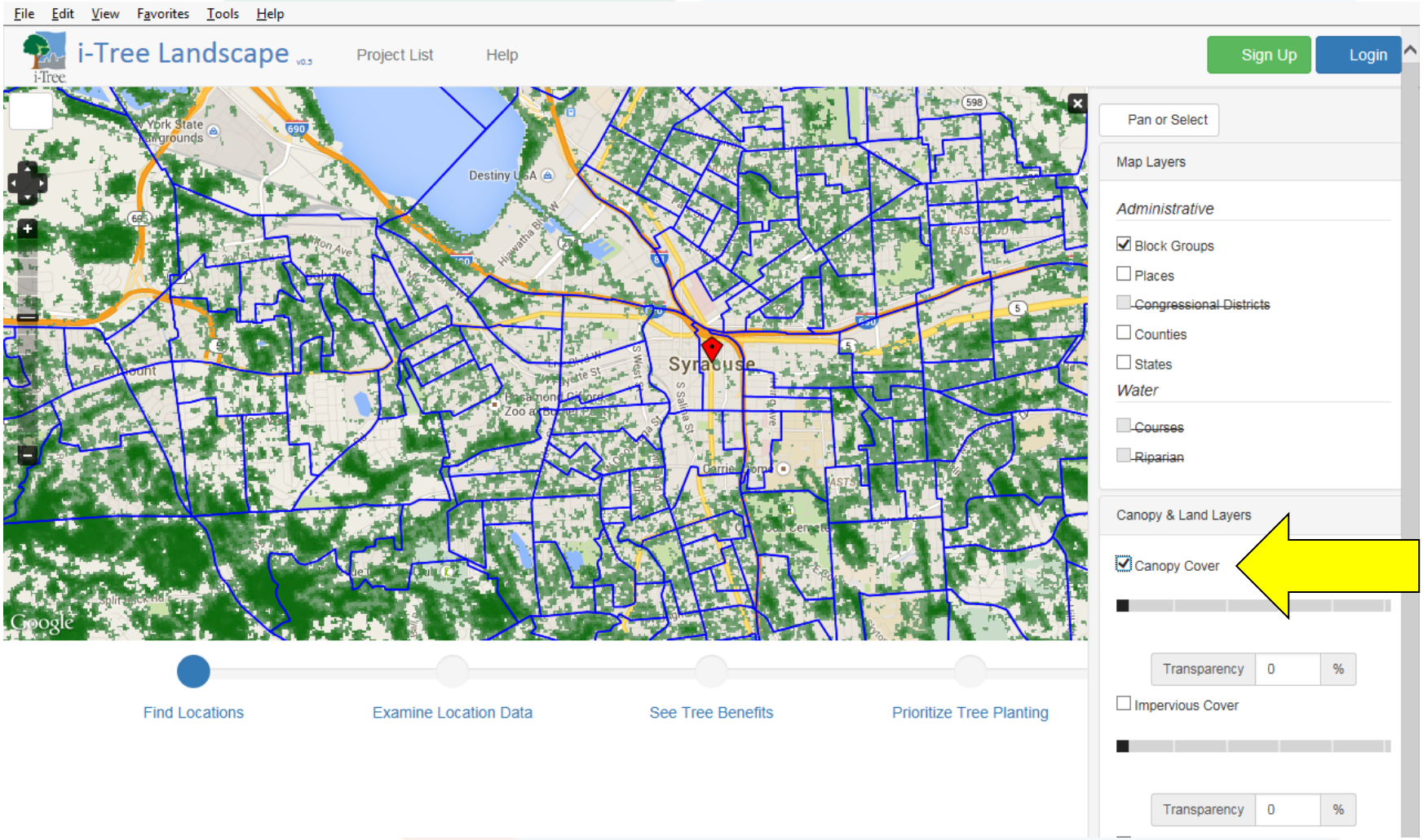


i-Tree Landscape – View Land Cover (NLCD)

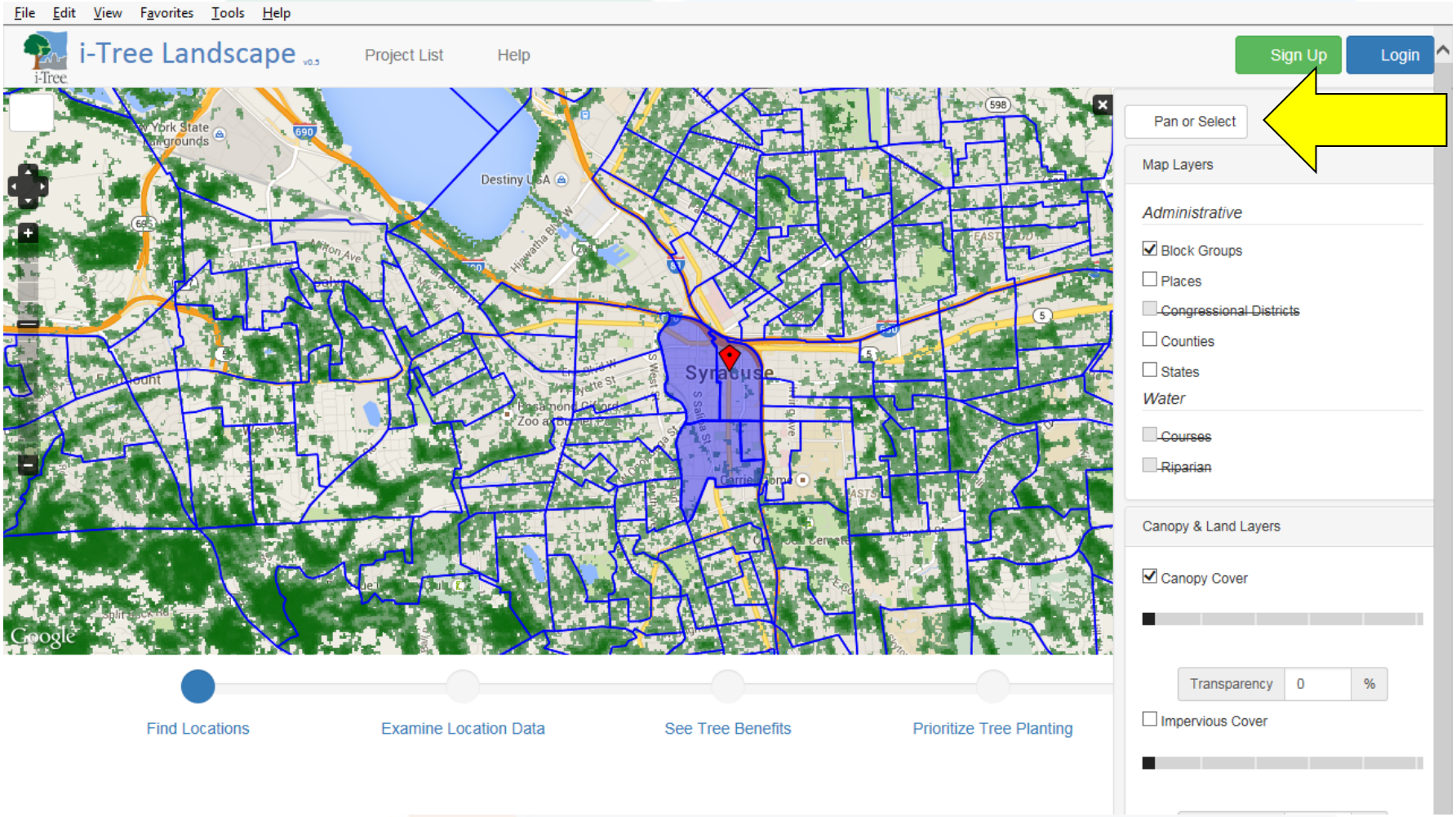


i-Tree Landscape

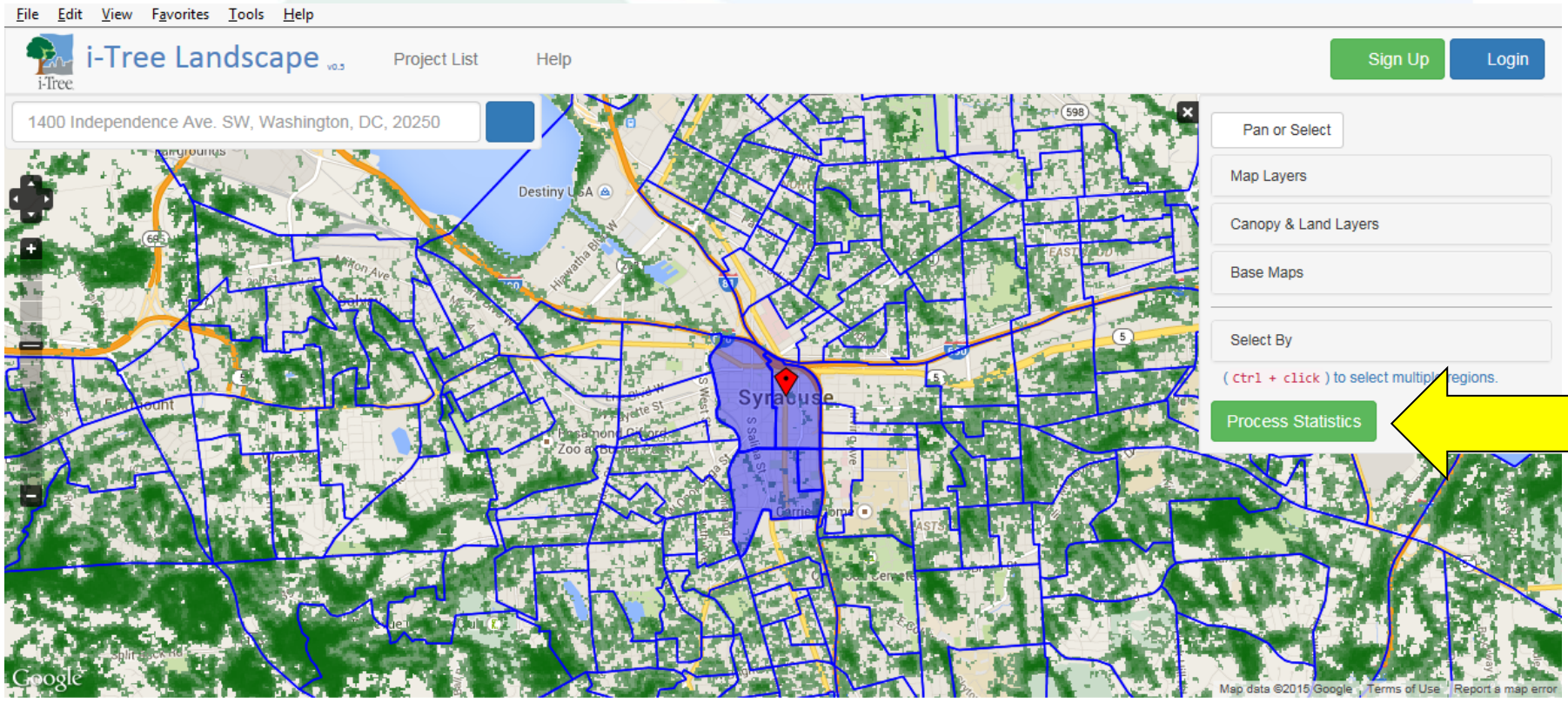
- See tree and/or impervious cover



i-Tree Landscape – Select Areas



i-Tree Landscape – Analyze Areas

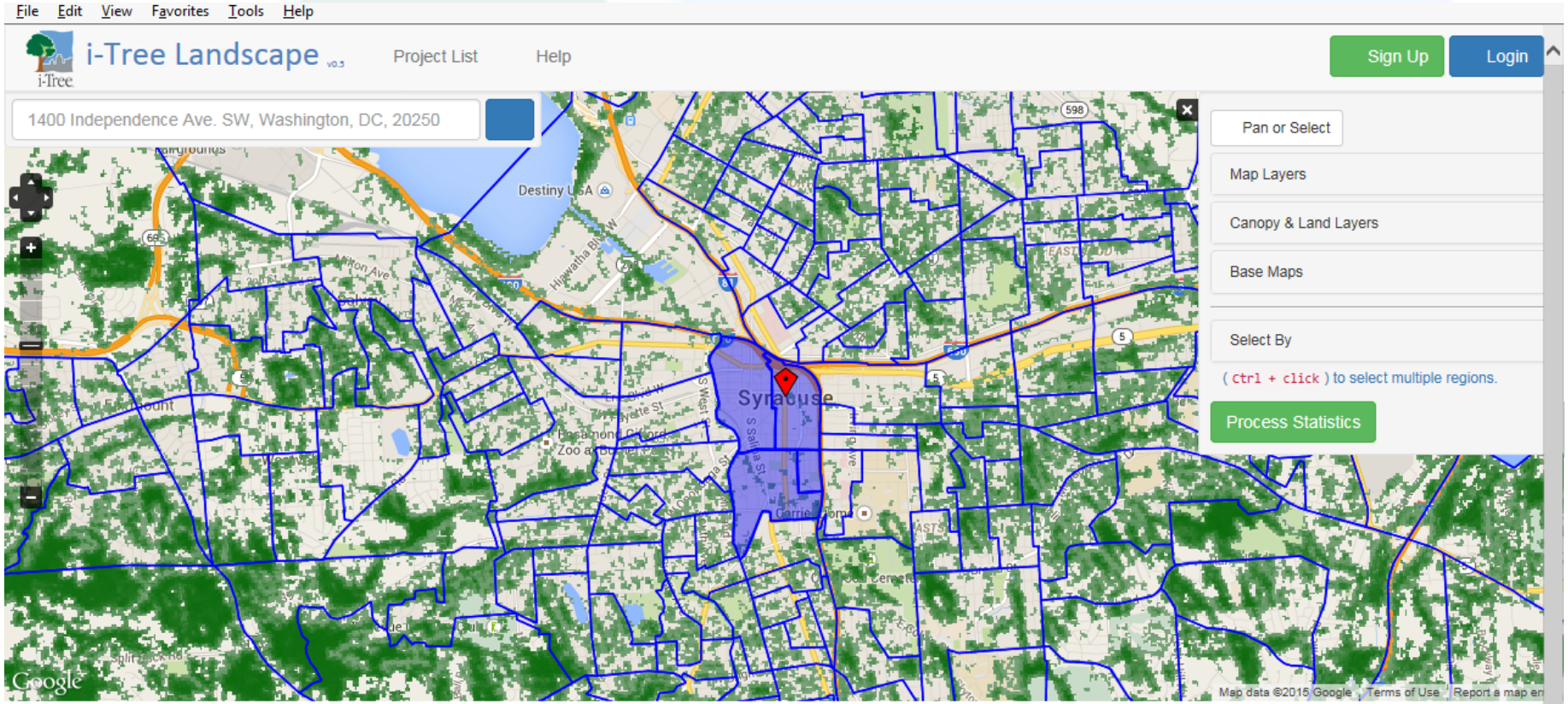


Find Locations — Examine Location Data — See Tree Benefits — Prioritize Tree Planting — Generate Results

Canopy & Impervious | Land Cover | Census Data

Region	Area (m^2)	Canopy Area (m^2)	Canopy Percent	Impervious Area (m^2)	Impervious Percent
Total	2144727.9	19006.0	0.9	1671608.2	77.9
360670042002	758404.4	14694.7	1.9	492052.1	64.9
360670042001	128610.8	1146.4	0.9	87959.0	68.4

i-Tree Landscape – Analyze Areas



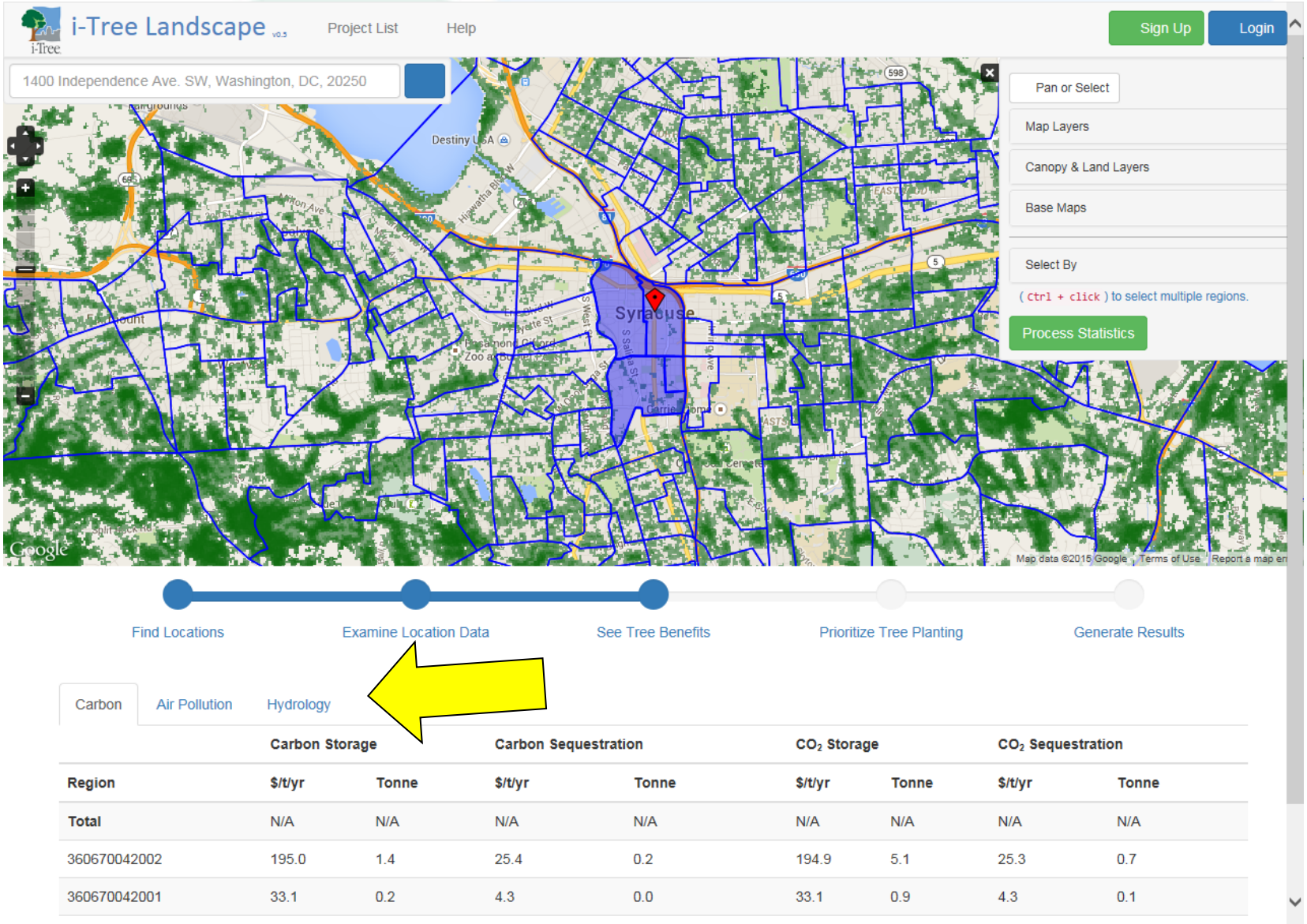
Find Locations | ...tion Data | See Tree Benefits | Prioritize Tree Planting | Generate Results

Canopy & Impervious | Land Cover | Census Data

Developed | Forest | Shrubland | Herbaceous | Planted/Cultivated | Barren | Wetlands | Water

	Developed, Open Space		Developed, Low Intensity		Developed, Medium Intensity		Developed, High Intensity	
Region	**m²**	**%**	**m²**	**%**	**m²**	**%**	**m²**	**%**
Total	17779.5		143935.1		627598.5		1355414.8	

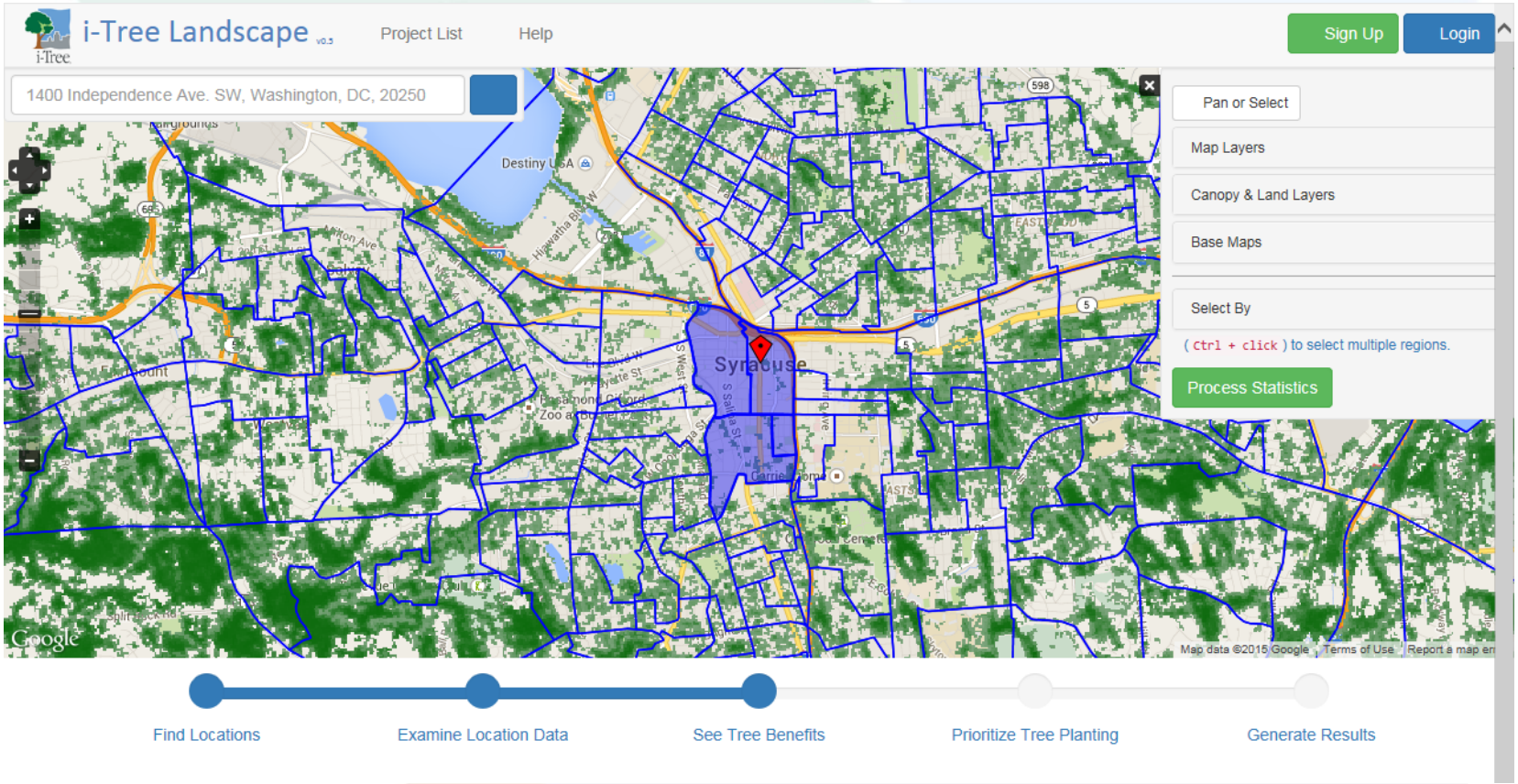
i-Tree Landscape – Analyze Ecosystem Services



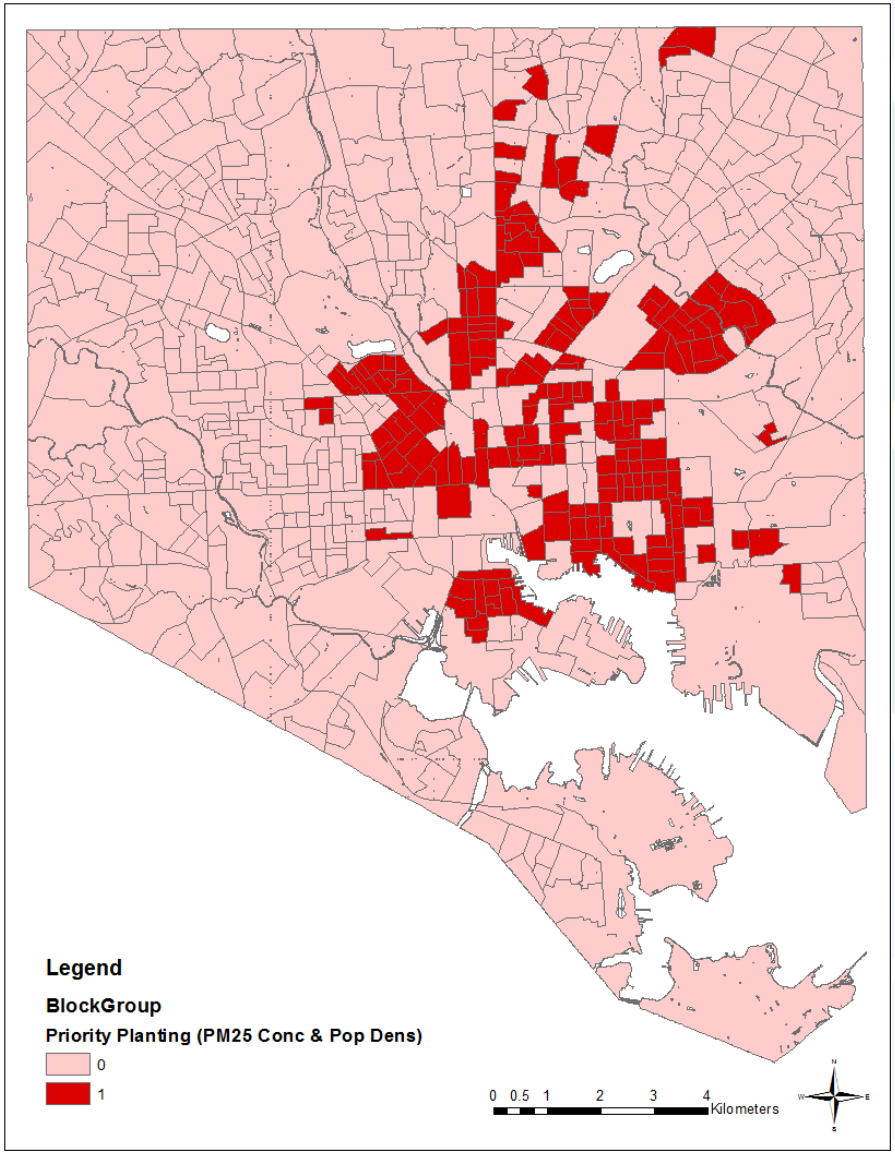
	Carbon Storage		Carbon Sequestration		CO_2 Storage		CO_2 Sequestration	
Region	**$/t/yr**	**Tonne**	**$/t/yr**	**Tonne**	**$/t/yr**	**Tonne**	**$/t/yr**	**Tonne**
Total	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
360670042002	195.0	1.4	25.4	0.2	194.9	5.1	25.3	0.7
360670042001	33.1	0.2	4.3	0.0	33.1	0.9	4.3	0.1

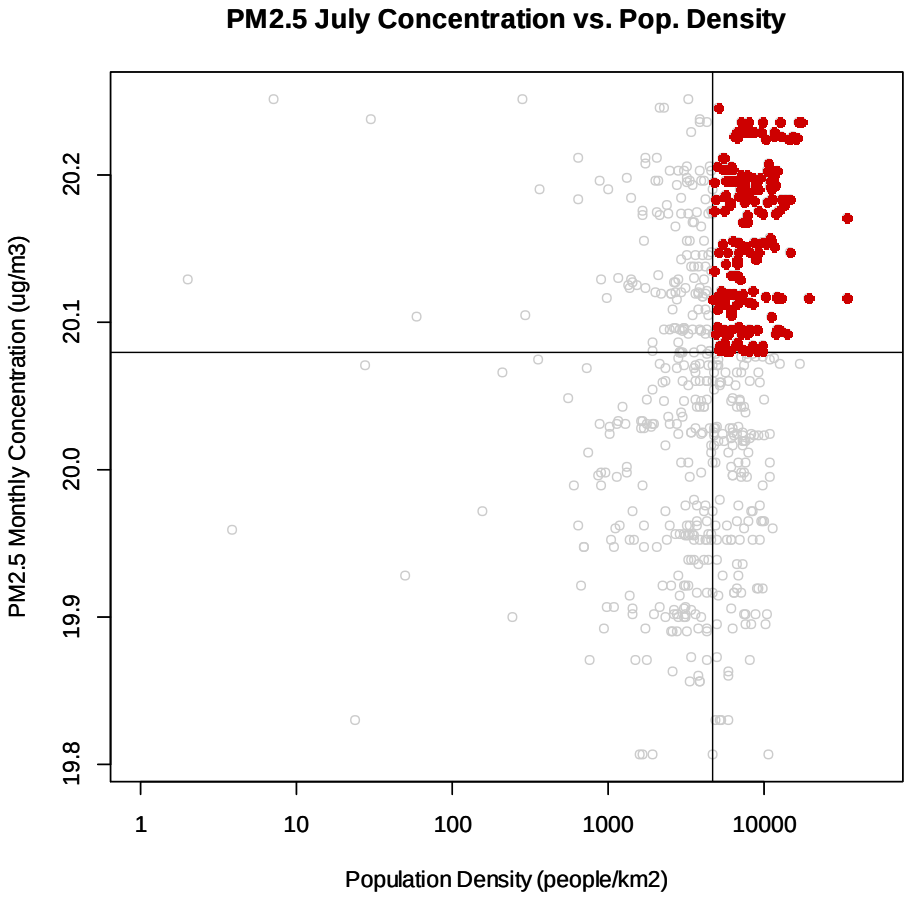
i-Tree Landscape

- Can change tree cover to see how services change
- Specify areas that meet criteria or custom areas
- Optimize for planting or protection
- Many layers to be added (e.g., soils, temperature, pollution)



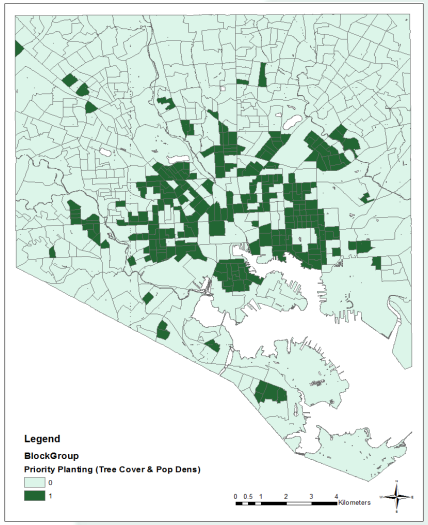
Air Pollution ($PM_{2.5}$) - Priority Planting



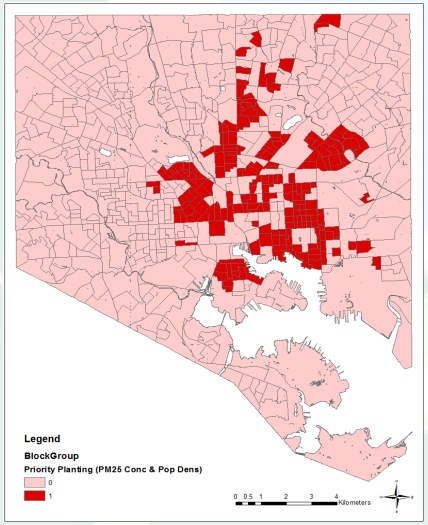


Priority Planting Block Groups

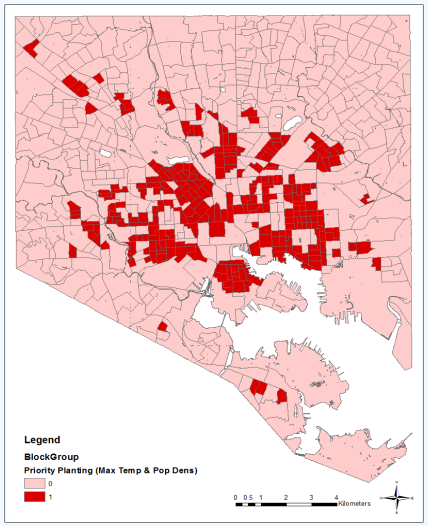
Tree Cover vs. Pop. Dens



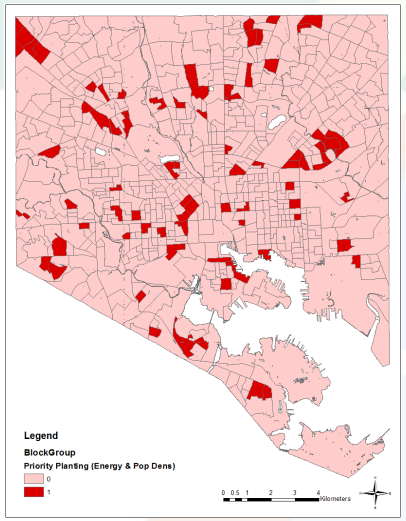
$PM_{2.5}$ Conc. vs. Pop. Dens



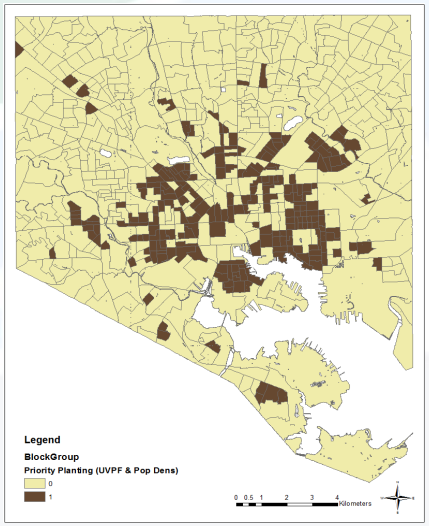
Max. Temp. vs. Pop. Dens



Thermal Comfort vs. Pop. Dens



UVPF vs. Pop. Dens



Upcoming Features

- Updated carbon equations (FIA, global)
- Biodiversity index
- Species ratings based on projected climate change
- UV reduction and health effects
- Air temperature reduction and health effects
- Human comfort
- Avoided emissions and health effects
- Pollen
- Nutrient cycling
- Urban soils
- Product potential
- Climate change projections
- New map layers in Landscape –links to Design
- Drought routines
- Grass analyses
- Enhanced differentiation by species
- Plot re-measurement analyses
- Wildlife

Improved Mobile Apps

- Accessibility
- Inventory
- Citizen science
- Education

i-Tree™

Do you?