RESEARCH ARTICLE

*J. For.* 116(2):164–177
doi: 10.1093/jofore/fvx004

urban & community forestry

# US Urban Forest Statistics, Values, and Projections

**David J. Nowak and Eric J. Greenfield**

U.S. urban land increased from 2.6% (57.9 million acres) in 2000 to 3.0% (68.0 million acres) in 2010. States with the greatest amount of urban growth were in the South/Southeast (TX, FL, NC, GA and SC). Between 2010 and 2060, urban land is projected to increase another 95.5 million acres to 163.1 million acres (8.6%) with 18 states projected to have an increase of over 2 million acres. Overall, there are an estimated 5.5 billion trees (39.4% tree cover) in urban areas nationally that contain 127 million acres of leaf area and 44 million tons of dry-weight leaf biomass. Annually, these trees produce a total of $18.3 billion in value related to air pollution removal ($5.4 billion), reduced building energy use ($5.4 billion), carbon sequestration ($4.8 billion) and avoided pollutant emissions ($2.7 billion). States with greatest annual urban forest values were: Florida ($1.9 billion), California ($1.4 billion), Pennsylvania ($1.1 billion), New York ($1.0 billion) and Ohio ($971 million).

**Keywords:** tree density, tree leaves, air pollution, energy use, RPA assessment

## Introduction

Urban forests are composed of all trees within urban areas. They differ from rural forests in that urban forests typically have a lower percent tree cover and density, with trees in closer association with numerous humans and built structures. Public trees within urban forests are often under varying degrees of governmental management, while private trees are managed by multiple landowners, often in relatively small parcels or management units. Even though much of the forest is privately managed, urban governments can influence private management via incentives, education, and regulations. A better understanding of these forests is important due to: a) the close proximity of these forests to over 80% of the US population, b) the substantial benefits these forests can bring related to mitigating issues associated with urbanization (e.g., heat islands, pollution, runoff), reducing the spread of issues into surrounding rural forests (e.g., pollution, invasive species, insects, and diseases), and enhancing human health and well-being, c) a current limited understanding of this resource, and d) the need for more informed management and policies related to urban forests from the local to national scale.

Urban forests vary in extent and composition across the United States. This forest variation along with differences in climate and human populations affects the magnitude and value of services provided by urban forests across the nation. Research on urban forests over the past several decades has advanced our understanding of this resource and its impact on society. These impacts include many ecosystem services and costs associated with vegetation in close proximity to people, many of which remain to be quantified. These services include moderating climate, reducing building energy use and atmospheric carbon dioxide ($CO_2$), improving air and water quality, mitigating rainfall runoff and flooding, enhancing human health and social well-being, and lowering noise impacts (Dwyer et al. 1992, Nowak and Dwyer 2007, Dobbs et al. 2017). Urban forests also have various costs associated with tree planting, maintenance, and removal, and other indirect costs such as allergies from tree pollen, increases in winter building energy use due to tree shade from both evergreen and deciduous trees, changes in local biodiversity due to invasive plants, and increased taxes due to increased property values (Roy et al. 2012, Lyytimaki 2017, Nowak 2017).

Urban forests have been estimated to provide billions of dollars in annual benefits to the United States, and these benefits (and costs) will continue to grow as urban areas expand into the surrounding rural landscapes. The purpose of this paper is to update and

Received April 12, 2017; accepted November 13, 2017.

**Affiliations:** *David J. Nowak (dnowak@fs.fed.us), Eric J. Greenfield (ejgreenfield@fs.fed.us), USDA Forest Service, 5 Moon Library, SUNY-ESF, Syracuse, NY 13210 Corresponding author, dnowak@fs.fed.us 315-448-3212*

**Acknowledgments:** *Funding for this project was provided in part by the U.S. Forest Service's RPA Assessment Research and Development Program and State & Private Forestry's Urban and Community Forestry Program. Thanks to Alexander Arams, Asante Holder, Christopher Maldonado, and Emily Proutey for assistance with photo-interpretation.*

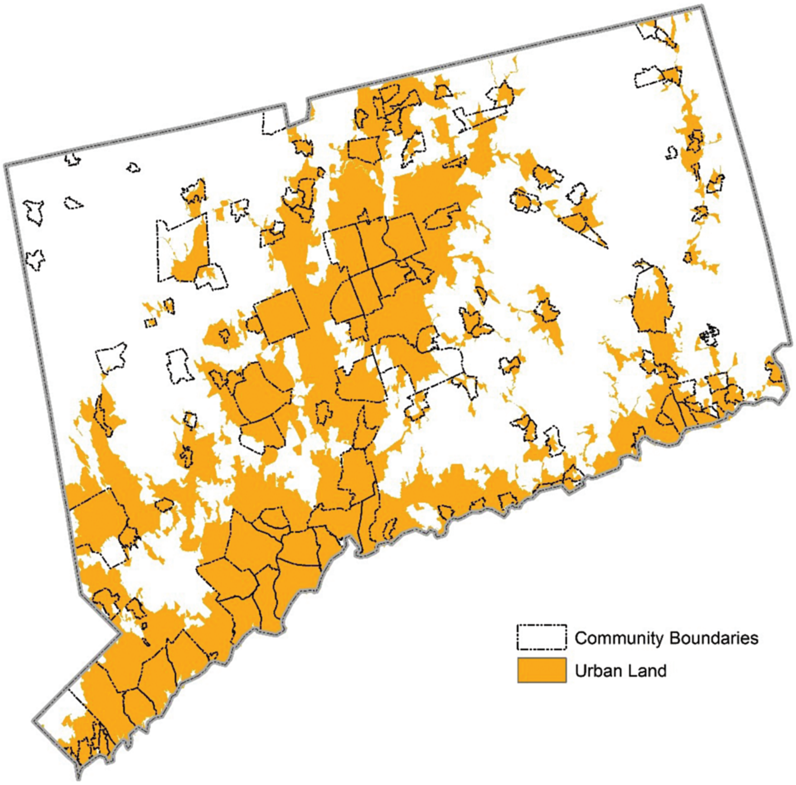

**Figure 1. Distribution of urban and community land in Connecticut (2010).**

summarize urban forest ecosystem services and values (i.e., pollution removal, carbon storage and sequestration, altered building energy use and power plant emissions) at the state and national level, as well as provide new state estimates on urban forest structure (i.e., tree cover, number of trees, leaf area, leaf biomass) and projections of urban land growth between 2010 and 2060. These statistics and projections can be used to help inform states on the value and magnitude of their urban forests, as well as guide state policies to help protect and enhance this valuable resource.

## Urban vs. Urban/Community Land (2000–2010)

Urban and urban/community areas were delimited using 2010 Census data and definitions. The definition of urban is primarily based on population density using the US Census Bureau's (2017a) definition: all territory, population, and housing units located within urbanized areas or urban clusters. Urban areas comprise a densely settled core of census tracts and/or census blocks that meet minimum population density requirements, along with adjacent territory containing non-residential urban land uses as well as territory with low population density included to link outlying densely settled territory with the densely settled core. To qualify as an urban area, the territory identified according to criteria must encompass at least 2,500 people, at least 1,500 of which reside outside institutional group quarters. The Census Bureau identifies two types of urban areas: a) Urbanized Areas of 50,000 or more people, and b) Urban Clusters of at least 2,500 and less than 50,000 people (US Census Bureau 2017a).

The definition of community, which includes cities, is based on jurisdictional or political boundaries delimited by US Census Bureau definitions of incorporated and designated places (US Census Bureau 2017a). Community areas may consist of all, some, or no urban land within their boundaries (Figure 1). Because urban land encompasses the more heavily populated areas (population density-based definition) and community land has varying amounts of urban land that are recognized by their geopolitical boundaries (political definition), the category of "urban/community" was created to classify the union of these two geographically overlapping definitions where most people live. Urban land is where the highest concentrations of people reside; urban/community is a larger geography that includes the urban land plus politically defined areas of communities (e.g., cities, villages). The urban/community definition was added because this area provides a more comprehensive portrayal of lands where people live and where trees and forests are managed in close proximity to people. This definition encompasses all communities, including less densely populated, more rural communities, along with densely populated urban areas. Understanding tree cover in both urban and urban/community areas is important for improving regional land management decisions. The estimates in this paper are for land area only (excluding major water bodies).

Urban land in 2010 occupied 3.0% (68.0 million acres) of the United States and 3.6% of the conterminous United States (67.6 million acres) (Table 1), while

### Management and Policy Implications

Urban forests provide numerous benefits to society. As urbanization and urban populations continue to expand across the nation, the importance of these benefits increases and will be essential for sustaining human population health and well-being. This urban expansion will not only affect urban forests, but also affects surrounding natural forests through an increasingly close association of rural forests with human populations and byproducts of an urbanizing landscape, such as air pollution, invasive plants and insects, fragmentation, and parcelization. By understanding how urbanization patterns vary across the nation, areas of potentially increasing conflicts with rural forests can be identified to help sustain rural forest integrity and health in the coming decades. With knowledge of how urban forest cover and benefits/values vary across the nation's landscape, state and national policies and management actions can be designed to sustain urban forest health and provide for optimal benefits distribution to a vastly urban society. Finally, as urban forests have various costs, understanding the cumulative magnitude of urban forest benefits and values in increasing detail will continue to improve our understanding of the potential return on investments of tree and forest management within urban and urbanizing landscapes.

**Table 1. State statistics on urban population, urban land growth (2000–2010) and urban tree cover. Bold numbers indicate that the state is within the top five highest values for that category.**

| | Urban population 2010 | | Urban land 2000 | | Urban land 2010 | | Change (2000–2010) | | Urban tree cover[*] | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| State | No. ($x10^3$) | %[†] | Ac. ($x10^3$) | %[‡] | Ac. ($x10^3$) | %[‡] | Ac. ($x10^3$) | %[‡] | % | SE | *n* |
| Alabama | 2820 | 59.0 | 1118 | 3.4 | 1417 | 4.4 | 299 | 0.9 | 42.2 | 2.6 | 367 |
| Arizona | 5740 | 89.8 | 1070 | 1.5 | 1399 | 1.9 | 328 | 0.5 | 26.1 | 2.8 | 238 |
| Arkansas | 1639 | 56.2 | 570 | 1.7 | 703 | 2.1 | 133 | 0.4 | 46.1 | 2.6 | 373 |
| California | **35,392** | **95.0** | **5007** | 5.0 | **5263** | 5.3 | 257 | 0.3 | 31.5 | 2.0 | 546 |
| Colorado | 4335 | 86.2 | 811 | 1.2 | 977 | 1.5 | 166 | 0.2 | 17.6 | 1.8 | 467 |
| Connecticut | 3145 | 88.0 | 1102 | **35.5** | 1168 | **37.7** | 66 | 2.1 | **61.6** | 1.6 | 906 |
| Delaware | 748 | 83.3 | 187 | 15.0 | 260 | **20.9** | 73 | **5.9** | 35.1 | 1.6 | 889 |
| Florida | **17,150** | 91.2 | **3713** | 10.8 | **4701** | 13.7 | **988** | **2.9** | 41.8 | 1.9 | 663 |
| Georgia | 7276 | 75.1 | 2340 | 6.4 | **3055** | 8.3 | **715** | 1.9 | **58.8** | 1.9 | 648 |
| Idaho | 1107 | 70.6 | 258 | 0.5 | 320 | 0.6 | 62 | 0.1 | 13.1 | 1.5 | 519 |
| Illinois | **11,356** | 88.5 | 2271 | 6.4 | 2526 | 7.1 | 256 | 0.7 | 31.3 | 1.7 | 753 |
| Indiana | 4695 | 72.4 | 1410 | 6.1 | 1615 | 7.0 | 205 | 0.9 | 31.4 | 1.7 | 768 |
| Iowa | 1950 | 64.0 | 519 | 1.5 | 609 | 1.7 | 90 | 0.3 | 27.2 | 2.2 | 423 |
| Kansas | 2117 | 74.2 | 551 | 1.1 | 623 | 1.2 | 73 | 0.1 | 34.7 | 2.0 | 585 |
| Kentucky | 2534 | 58.4 | 761 | 3.0 | 902 | 3.6 | 141 | 0.6 | 35.7 | 2.0 | 569 |
| Louisiana | 3319 | 73.2 | 974 | 3.5 | 1266 | 4.6 | 293 | 1.1 | 44.4 | 2.1 | 577 |
| Maine | 514 | 38.7 | 214 | 1.1 | 229 | 1.2 | 15 | 0.1 | **58.5** | 2.9 | 294 |
| Maryland | 5035 | 87.2 | 1074 | **17.3** | 1283 | 20.7 | 209 | **3.4** | 52.2 | 1.8 | 759 |
| Massachusetts | 6024 | **92.0** | 1706 | **34.2** | 1898 | **38.0** | 191 | **3.8** | **57.1** | 1.7 | 881 |
| Michigan | 7374 | 74.6 | 2111 | 5.8 | 2310 | 6.4 | 198 | 0.5 | 42.5 | 1.8 | 784 |
| Minnesota | 3888 | 73.3 | 953 | 1.9 | 1099 | 2.2 | 146 | 0.3 | 46.4 | 2.6 | 360 |
| Mississippi | 1466 | 49.4 | 590 | 2.0 | 713 | 2.4 | 123 | 0.4 | 45.3 | 2.4 | 428 |
| Missouri | 4216 | 70.4 | 1152 | 2.6 | 1314 | 3.0 | 162 | 0.4 | 39.1 | 2.1 | 550 |
| Montana | 553 | 55.9 | 165 | 0.2 | 190 | 0.2 | 25 | 0.0 | 21.4 | 4.5 | 84 |
| Nebraska | 1335 | 73.1 | 291 | 0.6 | 335 | 0.7 | 44 | 0.1 | 20.5 | 1.7 | 572 |
| Nevada | 2544 | **94.2** | 346 | 0.5 | 490 | 0.7 | 144 | 0.2 | 12.9 | 2.3 | 209 |
| New Hampshire | 794 | 60.3 | 349 | 6.1 | 412 | 7.2 | 63 | 1.1 | **56.3** | 2.0 | 631 |
| New Jersey | 8326 | **94.7** | 1706 | **36.2** | 1872 | **39.8** | 166 | **3.5** | 46.1 | 1.7 | 872 |
| New Mexico | 1594 | 77.4 | 480 | 0.6 | 530 | 0.7 | 49 | 0.1 | 16.8 | 2.3 | 274 |
| New York | **17,033** | 87.9 | 2439 | 8.1 | 2628 | 8.7 | 189 | 0.6 | 48.6 | 1.8 | 734 |
| North Carolina | 6303 | 66.1 | 2202 | 7.1 | 2949 | 9.5 | **747** | 2.4 | 52.4 | 1.9 | 716 |
| North Dakota | 403 | 59.9 | 91 | 0.2 | 118 | 0.3 | 27 | 0.1 | 10.1 | 1.8 | 267 |
| Ohio | 8987 | 77.9 | **2540** | 9.7 | 2828 | 10.8 | 289 | 1.1 | 37.6 | 1.7 | 780 |
| Oklahoma | 2484 | 66.2 | 729 | 1.7 | 837 | 1.9 | 107 | 0.2 | 24.3 | 2.7 | 255 |
| Oregon | 3103 | 81.0 | 651 | 1.1 | 708 | 1.2 | 57 | 0.1 | 30.8 | 1.9 | 611 |
| Pennsylvania | 9997 | 78.7 | **2696** | 9.4 | **3016** | 10.5 | 320 | 1.1 | 40.7 | 1.8 | 778 |
| Rhode Island | 955 | 90.7 | 237 | **35.9** | 256 | **38.7** | 18 | 2.8 | 50.6 | 1.7 | 911 |
| South Carolina | 3067 | 66.3 | 1152 | 6.0 | 1521 | 7.9 | **369** | 1.9 | 49.8 | 1.9 | 659 |
| South Dakota | 462 | 56.7 | 106 | 0.2 | 145 | 0.3 | 39 | 0.1 | 18.5 | 2.3 | 281 |
| Tennessee | 4214 | 66.4 | 1524 | 5.8 | 1858 | 7.0 | 334 | 1.3 | 41.1 | 2.1 | 528 |
| Texas | **21,299** | 84.7 | **4507** | 2.7 | **5586** | 3.3 | **1079** | 0.6 | 26.7 | 1.8 | 606 |
| Utah | 2504 | 90.6 | 428 | 0.8 | 581 | 1.1 | 153 | 0.3 | 14.9 | 2.0 | 308 |
| Vermont | 243 | 38.9 | 91 | 1.5 | 100 | 1.7 | 9 | 0.1 | 49.2 | 2.3 | 465 |
| Virginia | 6041 | 75.5 | 1481 | 5.9 | 1708 | 6.8 | 228 | 0.9 | 45.2 | 2.1 | 558 |
| Washington | 5655 | 84.1 | 1335 | 3.1 | 1521 | 3.6 | 186 | 0.4 | 35.1 | 1.9 | 618 |
| West Virginia | 902 | 48.7 | 358 | 2.3 | 410 | 2.7 | 51 | 0.3 | 49.7 | 2.1 | 543 |
| Wisconsin | 3992 | 70.2 | 1024 | 3.0 | 1204 | 3.5 | 180 | 0.5 | 27.7 | 2.0 | 502 |
| Wyoming | 365 | 64.8 | 107 | 0.2 | 124 | 0.2 | 17 | 0.0 | 11.9 | 2.6 | 159 |
| US48 | 247,597 | 80.7 | 57,531 | 3.0 | 67,616 | 3.6 | 10,085 | 0.5 | 39.3 | 0.4 | 27,268 |
| Alaska | 1250 | 66.0 | 164 | 0.0 | 166 | 0.0 | 2 | 0.0 | 47.4 | 6.6 | 57 |
| Hawaii | 469 | **91.9** | 224 | 5.4 | 250 | 6.1 | 26 | 0.6 | 41.7 | 2.8 | 319 |
| US50 | 249,316 | 80.7 | 57,919 | 2.6 | 68,032 | 3.0 | 10,113 | 0.4 | 39.4 | 0.4 | 27,644 |

[*] See Table 2 for average date of imagery by state, [†] percent of state population in urban land, [‡] percent of state land area.
US48 – conterminous US, US50 – entire US

urban/community land occupied 6.2% of the United States (141.0 million acres) and 6.4% of the conterminous United States (120.7 million acres) (Table 2). Urban land increased from 2.6% in 2000 to 3.0% in 2010 (3.0 to 3.6% in the conterminous United States). Urban/community land increased from 5.4% in 2000 to 6.2% in 2010 (5.4 to 6.4% in the conterminous United States).

The states with the greatest percent urban land (2010) are: New Jersey (39.8%), Rhode Island (38.7%), Massachusetts (38.0%), Connecticut (37.7%), and Delaware (20.9%). The states with the greatest amount of urban land are: Texas (5.6 million acres), California (5.3 million acres), Florida (4.7 million acres), Georgia (3.1 million acres), and Pennsylvania (3.0 million acres). States with the greatest percent urban land growth (2000–2010) are: Delaware (5.9%), Massachusetts (3.8%), New Jersey (3.5%), Maryland (3.4%), and Florida (2.9%). States with greatest amount of urban land growth are: Texas (1.1 million acres),

**Table 2. State statistics on urban/community (U/C) land growth (2000–2010) and urban/community tree cover. Bold numbers indicate that the state is within the top five highest values for that category. Sample size for tree cover estimate was 1000 points per state, except for Alaska (492 points due to poor resolution [uninterpretable] imagery).**

| | U/C Land 2000 | | U/C Land 2010 | | Change (2000–2010) | | U/C Tree cover | | |
|---|---|---|---|---|---|---|---|---|---|
| State | Acres (x10³) | %* | Acres (x10³) | %* | Acres (x10³) | %* | % | SE | Date† |
| Alabama | 3147 | 9.7 | 4029 | 12.4 | 882 | 2.7 | 49.7 | 1.6 | 2014 |
| Arizona | **3883** | 5.3 | **5623** | 7.7 | **1740** | 2.4 | 30.2 | 1.5 | 2014 |
| Arkansas | 1516 | 4.6 | 1782 | 5.4 | 265 | 0.8 | 46.9 | 1.6 | 2014 |
| California | **8529** | 8.6 | **9861** | 9.9 | **1332** | 1.3 | 39.0 | 1.5 | 2014 |
| Colorado | 1743 | 2.6 | 2029 | 3.1 | 286 | 0.4 | 21.6 | 1.3 | 2013 |
| Connecticut | 1236 | **39.9** | 1286 | **41.5** | 50 | 1.6 | **62.7** | 1.5 | 2014 |
| Delaware | 222 | 17.8 | 293 | 23.5 | 70 | **5.6** | 35.3 | 1.5 | 2012 |
| Florida | **5506** | 16.0 | **6948** | 20.2 | **1442** | **4.2** | 47.6 | 1.6 | 2014 |
| Georgia | 3541 | 9.6 | 4708 | 12.8 | **1167** | **3.2** | **61.4** | 1.5 | 2014 |
| Idaho | 438 | 0.8 | 606 | 1.1 | 168 | 0.3 | 13.8 | 1.1 | 2014 |
| Illinois | 3085 | 8.7 | 3457 | 9.7 | 373 | 1.0 | 29.9 | 1.4 | 2013 |
| Indiana | 1867 | 8.1 | 2146 | 9.4 | 279 | 1.2 | 30.1 | 1.5 | 2013 |
| Iowa | 1302 | 3.6 | 1436 | 4.0 | 135 | 0.4 | 20.9 | 1.3 | 2014 |
| Kansas | 947 | 1.8 | 1113 | 2.1 | 167 | 0.3 | 30.3 | 1.5 | 2014 |
| Kentucky | 1301 | 5.1 | 1564 | 6.2 | 263 | 1.0 | 38.9 | 1.5 | 2014 |
| Louisiana | 1893 | 6.8 | 2213 | 8.0 | 320 | 1.2 | 47.3 | 1.6 | 2014 |
| Maine | 827 | 4.2 | 849 | 4.3 | 22 | 0.1 | **68.1** | 1.5 | 2014 |
| Maryland | 1455 | **23.4** | 1704 | **27.4** | 249 | **4.0** | 53.1 | 1.6 | 2014 |
| Massachusetts | 2001 | **40.1** | 2142 | **42.9** | 141 | 2.8 | 58.4 | 1.6 | 2014 |
| Michigan | 2638 | 7.3 | 2934 | 8.1 | 295 | 0.8 | 45.9 | 1.6 | 2014 |
| Minnesota | 2627 | 5.2 | 2949 | 5.8 | 322 | 0.6 | 46.7 | 1.6 | 2014 |
| Mississippi | 1409 | 4.7 | 1671 | 5.6 | 262 | 0.9 | 52.7 | 1.6 | 2015 |
| Missouri | 2064 | 4.7 | 2330 | 5.3 | 267 | 0.6 | 39.7 | 1.5 | 2015 |
| Montana | 1900 | 2.0 | 2366 | 2.5 | 466 | 0.5 | 37.2 | 1.5 | 2014 |
| Nebraska | 472 | 1.0 | 563 | 1.1 | 90 | 0.2 | 18.8 | 1.2 | 2014 |
| Nevada | 1931 | 2.7 | 2248 | 3.2 | 316 | 0.5 | 26.8 | 1.4 | 2015 |
| New Hampshire | 590 | 10.3 | 662 | 11.5 | 71 | 1.2 | **63.0** | 1.5 | 2015 |
| New Jersey | 2080 | **44.2** | 2155 | **45.8** | 75 | 1.6 | 47.8 | 1.6 | 2013 |
| New Mexico | 1303 | 1.7 | 1986 | 2.6 | 683 | 0.9 | 22.1 | 1.3 | 2015 |
| New York | 3259 | 10.8 | 3539 | 11.7 | 279 | 0.9 | 52.4 | 1.6 | 2013 |
| North Carolina | 3198 | 10.3 | 4097 | 13.2 | 899 | 2.9 | 54.2 | 1.6 | 2015 |
| North Dakota | 404 | 0.9 | 454 | 1.0 | 51 | 0.1 | 10.1 | 1.0 | 2014 |
| Ohio | 3295 | 12.6 | 3614 | 13.8 | 320 | 1.2 | 38.2 | 1.5 | 2014 |
| Oklahoma | 3001 | 6.8 | 3238 | 7.4 | 237 | 0.5 | 34.0 | 1.5 | 2015 |
| Oregon | 949 | 1.5 | 1151 | 1.9 | 202 | 0.3 | 33.9 | 1.5 | 2014 |
| Pennsylvania | 3550 | 12.4 | 3930 | 13.7 | 380 | 1.3 | 46.2 | 1.6 | 2013 |
| Rhode Island | 258 | **39.1** | 286 | **43.2** | 28 | **4.2** | 52.3 | 1.6 | 2015 |
| South Carolina | 1780 | 9.3 | 2255 | 11.7 | 475 | 2.5 | 53.6 | 1.6 | 2014 |
| South Dakota | 421 | 0.9 | 564 | 1.2 | 144 | 0.3 | 13.6 | 1.1 | 2014 |
| Tennessee | 2807 | 10.6 | 3355 | 12.7 | 549 | 2.1 | 46.9 | 1.6 | 2013 |
| Texas | **8286** | 5.0 | **9256** | 5.5 | 970 | 0.6 | 28.3 | 1.4 | 2015 |
| Utah | 1458 | 2.8 | 1782 | 3.4 | 324 | 0.6 | 16.6 | 1.2 | 2015 |
| Vermont | 168 | 2.9 | 207 | 3.5 | 39 | 0.7 | 56.6 | 1.6 | 2015 |
| Virginia | 2479 | 9.8 | 2972 | 11.8 | 493 | 2.0 | 51.0 | 1.6 | 2014 |
| Washington | 2202 | 5.2 | 2394 | 5.6 | 192 | 0.5 | 41.6 | 1.6 | 2015 |
| West Virginia | 633 | 4.1 | 718 | 4.7 | 85 | 0.5 | **61.3** | 1.5 | 2014 |
| Wisconsin | 1939 | 5.6 | 2340 | 6.8 | 401 | 1.2 | 38.3 | 1.5 | 2015 |
| Wyoming | 1196 | 1.9 | 808 | 1.3 | -388 | -0.6 | 15.8 | 1.2 | 2014 |
| US48 | 102,775 | 5.4 | 120,656 | 6.4 | 17,881 | 0.9 | 41.1 | 0.3 | 2014 |
| Alaska | **18,203** | 5.0 | **19,571** | 5.4 | **1367** | 0.4 | 48.8 | 2.3 | 2012 |
| Hawaii | 702 | 17.1 | 751 | 18.3 | 49 | 1.2 | 50.1 | 1.6 | 2015 |
| US50 | 121,681 | 5.4 | 140,978 | 6.2 | 19,297 | 0.9 | 42.2 | 0.4 | 2014 |

* Percent of state land area, † average date of imagery.
US48 – conterminous US; US50 – entire US

Florida (988,000 acres), North Carolina (747,000 acres), Georgia (715,000 acres), and South Carolina (369,000 acres). Overall, US urban land increased by 0.4% (10.11 million acres) and 0.5% (10.09 million acres) in the conterminous United States (Table 1).

The states with the greatest percent urban/community land (2010) are: New Jersey (45.8%), Rhode Island (43.2%), Massachusetts (42.9%), Connecticut (41.5%), and Maryland (27.4%). The states with the greatest amount of urban/community land are: Alaska (19.6 million acres), California (9.9 million acres), Texas (9.3 million acres), Florida (6.9 million acres), and Arizona (5.6 million acres). States with the greatest percent urban/community land growth (2000–2010) are: Delaware (5.6%), Florida (4.2%), Rhode Island (4.2%), Maryland (4.0%), and Georgia (3.2%). States with the greatest amount of urban/community land growth are: Arizona (1.7 million acres), Florida (1.4 million acres), Alaska (1.4 million acres), California (1.3

million acres), and Georgia (1.2 million acres). Overall US urban/community land increased by 0.9% (19.3 million acres) and 0.9% (17.9 million acres) in the conterminous United States (Table 2).

The states with the greatest percent urban land are all along the northeastern Atlantic coast, with large populations and relatively small state area: New Jersey, Rhode Island, Massachusetts, Connecticut, and Delaware. The impact of current urban forests is likely greatest in these areas due to the relatively large proportion of urban land. The largest states tend to have the most urban and/or urban/community land. Alaska has the most urban/community land due to its large overall area and large area within census-designated places (communities). The largest community in Alaska is Sitka city and borough (1.8 million acres), which is larger than the state of Delaware. States with the greatest amount of urban land growth in the last decade were in the South/Southeast (Texas, Florida, North Carolina, Georgia, South Carolina). The impact of expanding urban forests will likely be greatest in this region due to the relatively high rate of urban expansion and tree cover. The relatively large expansion of urban forests in this region is having, and will likely continue to have, substantial impacts on both humans and rural forest stands.

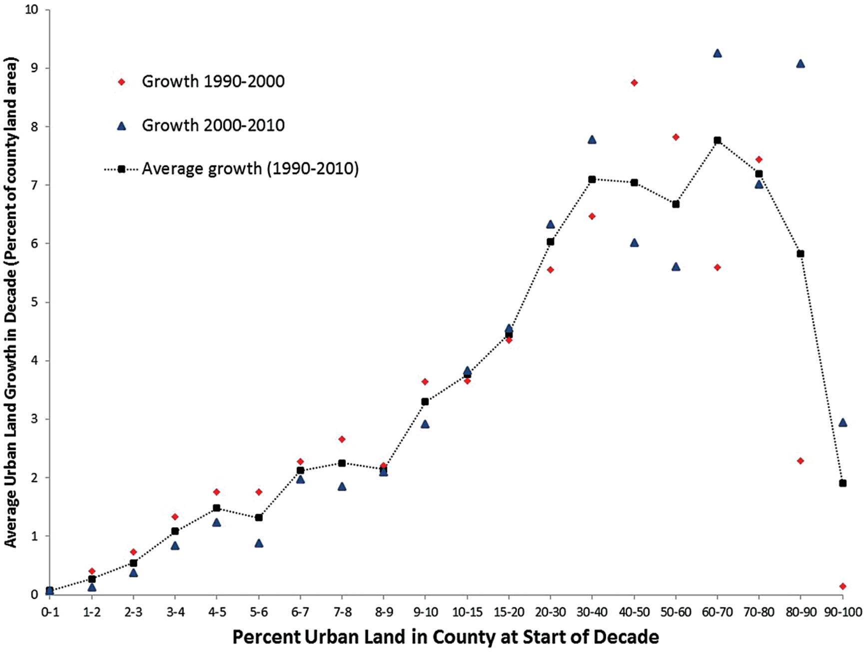

**Figure 2. Average increase in percent of county classified as urban (1990–2000; 2000–2010; average: 1990–2010) categorized by percent of county that was urban. Small counties (less than 56 mi²) were excluded from the analysis to limit large percent changes from minimal urban growth.**

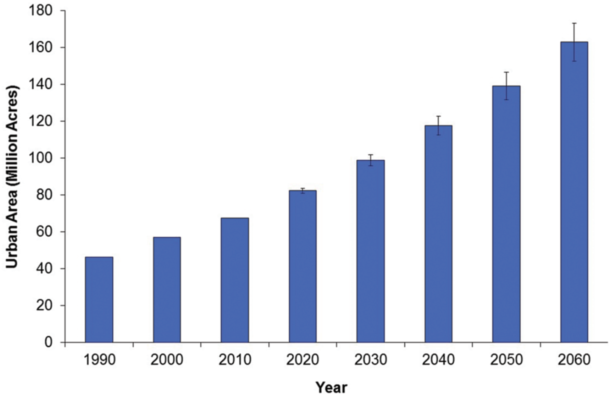

**Figure 3. Projected percent of land classified as urban in the conterminous United States. Error bars indicate estimate given plus or minus one standard error of growth.**

## Projected US Urban Area Growth (2010–2060)

Urban land projections were developed using the average projected urban decadal area growth by county (1990–2010) based on percent of county classified as urban at the start of the decade (Figure 2). That is, the average decadal growth in percent urban land (1990–2010) was applied to each percent urban county class (e.g., 5–6% urban land at start of decade) to project urban growth for each decade through 2060. These projections are only for the conterminous United States, due to data limitations in the original assessment (Nowak and Walton 2005) for Alaska and Hawaii. Methods follow the approach used in Nowak and Walton (2005), which estimated urban land growth from 2000 to 2050.

Decadal urban land growth rates increase as amount of urban land increases in counties from 0 to 30% urban land (Figure 2), indicating an acceleration of urban growth through time. The growth rates then tend to level out at around 7% per decade for counties with between 30 and 80% urban land and then decrease in counties with greater than 80% urban land as most of the available land has been urbanized. This acceleration pattern, along with the general increase in growth rates in counties with greater than 10% urban land between 1990–2000 and 2000–2010, indicate that urban expansion will be substantially greater in the counties that already have most of the urban land. The more rapid urbanization in the most urbanized regions likely has to do with greater populations, land area, and infrastructure upon which urbanization can expand. Areas with more urban land have a greater edge to expand infrastructure into surrounding rural areas via development. These expansion patterns and amounts are comparable to projections from more developed countries (e.g., Angel et al. 2011).

The updated urban projections reveal that urban land in the conterminous United States is projected to increase from 3.6% (67.6 million acres) in 2010 to 8.6% (163.1 million acres) in 2060 (Figure 3). This projected increase is 95.5 million acres over 50 years and is an increase in urban land larger than the state of Montana.

**Table 3. Projected urban land growth 2010–2060 by state for the conterminous United States. Bold numbers indicate that the state is within the top five highest values for that category.**

| | Percent urban land | | | | | | Projected increase (2010–2060) | |
|---|---|---|---|---|---|---|---|---|
| State | 2010 | 2020 | 2030 | 2040 | 2050 | 2060 | Acres (x10$^3$) | %[*] |
| Alabama | 4.4 | 5.5 | 6.9 | 8.5 | 10.3 | 12.5 | 2650 | 8.2 |
| Arizona | 1.9 | 2.5 | 3.0 | 3.9 | 4.8 | 5.9 | 2891 | 4.0 |
| Arkansas | 2.1 | 2.7 | 3.3 | 4.2 | 5.2 | 6.4 | 1431 | 4.3 |
| California | 5.3 | 6.6 | 8.2 | 9.9 | 12.0 | 14.4 | **9129** | 9.2 |
| Colorado | 1.5 | 1.9 | 2.4 | 3.0 | 3.7 | 4.5 | 2035 | 3.1 |
| Connecticut | **37.7** | **43.6** | **49.6** | **55.6** | **60.9** | **65.3** | 855 | **27.6** |
| Delaware | **20.9** | **25.4** | **30.3** | **36.7** | **43.0** | **50.1** | 365 | **29.3** |
| Florida | 13.7 | 17.2 | 20.5 | 24.0 | 27.8 | 31.6 | **6154** | 17.9 |
| Georgia | 8.3 | 9.7 | 11.3 | 12.9 | 14.8 | 16.9 | 3183 | 8.6 |
| Idaho | 0.6 | 0.8 | 1.0 | 1.3 | 1.6 | 2.0 | 733 | 1.4 |
| Illinois | 7.1 | 8.2 | 9.6 | 11.0 | 12.8 | 14.8 | 2716 | 7.6 |
| Indiana | 7.0 | 8.5 | 10.3 | 12.4 | 14.8 | 17.5 | 2405 | 10.5 |
| Iowa | 1.7 | 2.1 | 2.7 | 3.3 | 4.0 | 5.0 | 1177 | 3.3 |
| Kansas | 1.2 | 1.5 | 1.8 | 2.2 | 2.6 | 3.1 | 1012 | 1.9 |
| Kentucky | 3.6 | 4.4 | 5.4 | 6.5 | 7.8 | 9.4 | 1480 | 5.9 |
| Louisiana | 4.6 | 5.7 | 7.0 | 8.6 | 10.5 | 12.8 | 2267 | 8.2 |
| Maine | 1.2 | 1.5 | 1.9 | 2.4 | 3.0 | 3.7 | 510 | 2.6 |
| Maryland | 20.7 | 24.3 | 28.5 | 33.0 | 37.8 | 42.5 | 1359 | 21.9 |
| Massachusetts | **38.0** | **43.5** | **48.1** | **52.3** | **56.5** | **60.7** | 1131 | **22.7** |
| Michigan | 6.4 | 7.7 | 9.1 | 10.7 | 12.4 | 14.4 | 2896 | 8.0 |
| Minnesota | 2.2 | 2.6 | 3.1 | 3.6 | 4.2 | 4.9 | 1413 | 2.8 |
| Mississippi | 2.4 | 3.0 | 3.8 | 4.8 | 6.0 | 7.4 | 1519 | 5.1 |
| Missouri | 3.0 | 3.6 | 4.3 | 5.1 | 6.1 | 7.2 | 1858 | 4.2 |
| Montana | 0.2 | 0.3 | 0.4 | 0.5 | 0.7 | 0.8 | 563 | 0.6 |
| Nebraska | 0.7 | 0.9 | 1.1 | 1.3 | 1.6 | 1.9 | 577 | 1.2 |
| Nevada | 0.7 | 0.9 | 1.2 | 1.6 | 1.9 | 2.1 | 971 | 1.4 |
| New Hampshire | 7.2 | 8.9 | 10.7 | 12.8 | 15.1 | 17.7 | 600 | 10.5 |
| New Jersey | **39.8** | **44.7** | **49.6** | **54.4** | **58.6** | **62.4** | 1065 | **22.6** |
| New Mexico | 0.7 | 0.9 | 1.1 | 1.3 | 1.6 | 2.0 | 1024 | 1.3 |
| New York | 8.7 | 10.3 | 12.1 | 14.1 | 16.2 | 18.6 | 2974 | 9.9 |
| North Carolina | 9.5 | 11.5 | 13.9 | 16.6 | 19.7 | 23.1 | **4247** | 13.6 |
| North Dakota | 0.3 | 0.4 | 0.5 | 0.6 | 0.8 | 1.0 | 321 | 0.7 |
| Ohio | 10.8 | 12.8 | 15.1 | 17.6 | 20.4 | 23.5 | 3327 | 12.7 |
| Oklahoma | 1.9 | 2.3 | 2.8 | 3.4 | 4.1 | 4.9 | 1304 | 3.0 |
| Oregon | 1.2 | 1.4 | 1.8 | 2.3 | 2.8 | 3.4 | 1380 | 2.2 |
| Pennsylvania | 10.5 | 12.6 | 15.0 | 17.7 | 20.6 | 23.9 | **3816** | 13.3 |
| Rhode Island | **38.7** | **46.0** | **52.6** | **59.3** | **66.6** | **73.5** | 230 | **34.8** |
| South Carolina | 7.9 | 9.9 | 12.3 | 15.0 | 18.1 | 21.6 | 2626 | 13.6 |
| South Dakota | 0.3 | 0.4 | 0.6 | 0.7 | 0.9 | 1.1 | 402 | 0.8 |
| Tennessee | 7.0 | 8.6 | 10.4 | 12.4 | 14.8 | 17.4 | 2744 | 10.4 |
| Texas | 3.3 | 4.1 | 4.8 | 5.7 | 6.7 | 7.8 | **7424** | 4.4 |
| Utah | 1.1 | 1.4 | 1.7 | 2.1 | 2.5 | 2.9 | 946 | 1.8 |
| Vermont | 1.7 | 2.1 | 2.6 | 3.3 | 4.0 | 5.0 | 195 | 3.3 |
| Virginia | 6.8 | 7.9 | 9.1 | 10.5 | 12.0 | 13.8 | 1777 | 7.0 |
| Washington | 3.6 | 4.5 | 5.6 | 6.9 | 8.4 | 9.9 | 2689 | 6.3 |
| West Virginia | 2.7 | 3.4 | 4.4 | 5.5 | 6.9 | 8.4 | 887 | 5.8 |
| Wisconsin | 3.5 | 4.3 | 5.2 | 6.3 | 7.6 | 9.2 | 1969 | 5.7 |
| Wyoming | 0.2 | 0.3 | 0.4 | 0.4 | 0.5 | 0.6 | 260 | 0.4 |
| US48 | 3.6 | 4.4 | 5.2 | 6.2 | 7.4 | 8.6 | 95,485 | 5.0 |

US48 – conterminous US

[*] Growth in percent urban land (2010–2060).

Average urban area growth over this period is 1.9 million acres per year, starting at 1.5 million acres per year in 2010–2020 and increasing to 2.4 million acres per year in 2050–2060. To put this growth in perspective, the land area of Delaware is 1.25 million acres.

States with the greatest projected increase in percent urban land (2010–2060) are: Rhode Island (34.8%), Delaware (29.3%), Connecticut (27.6%), Massachusetts (22.7%), and New Jersey (22.6%). These states also had the greatest percent urban land in 2010 and are all projected to have at least 50% urban land by 2060. States with the greatest amount of urban land growth are projected to be: California (9.1 million acres), Texas (7.4 million acres), Florida (6.2 million acres), North Carolina (4.2 million acres), and Pennsylvania (3.8 million acres) (Table 3; Figures 4–5). The urban increase in each of these states over the 50-year period is greater than the land area of Connecticut (3.1 million acres). Eighteen states are projected to have an increase of over 2 million acres of urban land between 2010 and 2060.

These projections are based on national average urban area growth within counties with varying levels of urbanization, and assume the growth trends of 1990–2010 will continue, by decade, until 2060. Using a national average to project urban land growth will underpredict growth in areas that develop rapidly (above-average growth relative to their percent urban land) in the next several decades and overpredict growth in areas with below-average development relative to their percent urban land. The projections also increase in uncertainty the further the projections go into the future. However, the projections reveal a likely pattern of development across the landscape if past growth trends continue. These trends may vary in the future given changes in land development policies (e.g., SmartGrowth initiatives), changes in land value, interest rates, fuel prices, ecosystem limitations (e.g., water shortages), population growth rates, and other social, economic, or environmental factors. Although various factors may alter the projections of urban land growth, increasing rates and amounts of urban development and associated transformation of forest and other land cover types will occur in the future (US Forest Service 2016a).

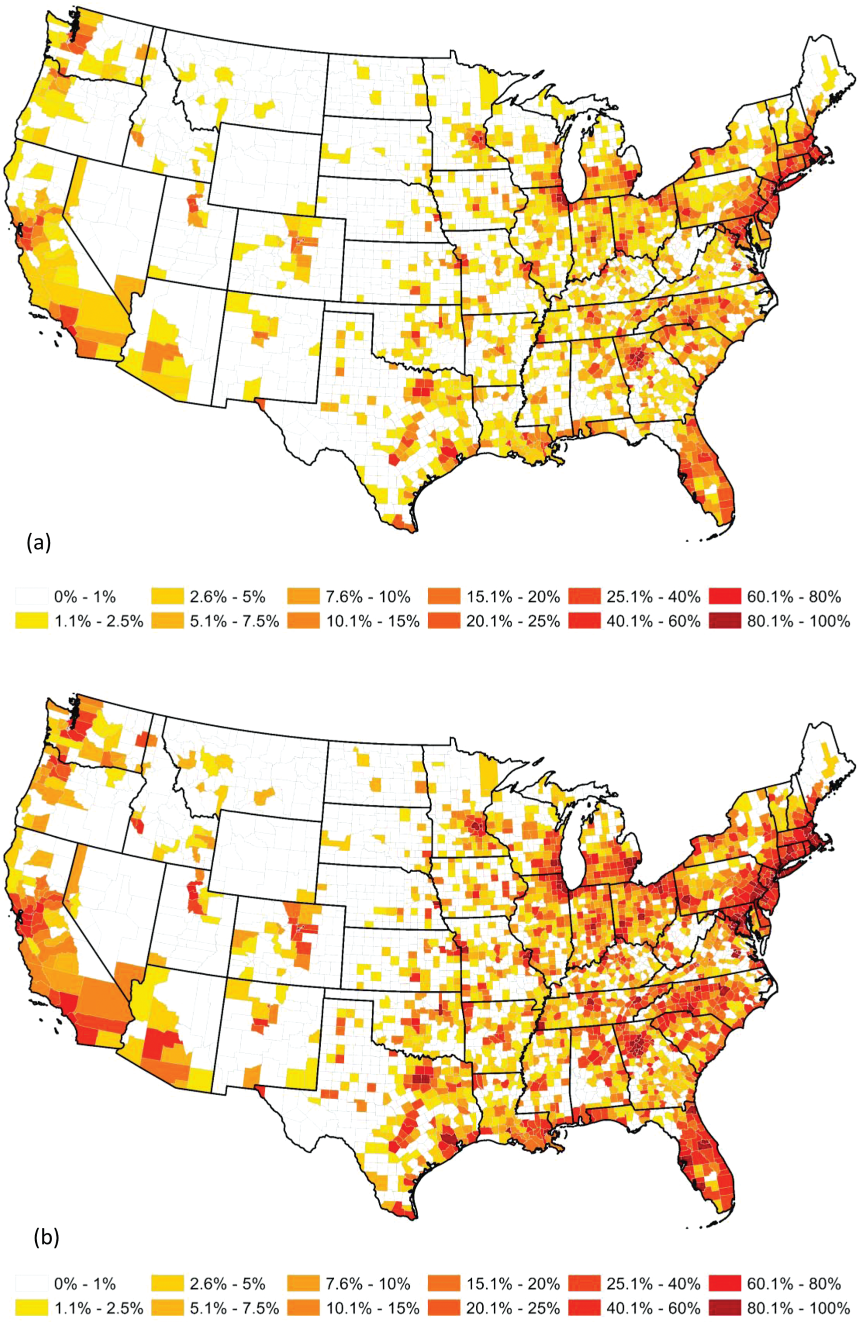

**Figure 4. (a) Percent of land classified as urban in 2010, and (b) projected percent of land classified as urban in 2060, by county.**

The average urban land growth over two decades (1990–2010) resulted in a slight decline in projected land growth compared with applying the same methods using only data from 1990 to 2000 (Nowak and Walton 2005). The previous projections estimated 8.1% of the conterminous United States to be urban by 2050, whereas the updated projections estimate 7.4% urban land in 2050. This reduction in urban estimates is mainly due to the reduced urban land growth rates between 1990–2000 and 2000–2010 in counties with less than 10% urban land (Figure 2). While growth rates decreased in those counties, growth rates between decades generally increased in counties with greater than 10% urban land. As most of the US counties (2,674 out of 3,067 counties; 87%) have less than 10% urban land, this distribution led to a decline in growth rates between the decades. The decline in growth rates between 1990–2000 and 2000–2010 may also be due, in part, to the 2008 economic recession. Between 2007 and 2009, annual new privately owned housing unit starts declined from 1.36 million to 554,000 (US Census 2017b). The housing rates have been on the rise since 2009, but are still lower than the rates in the mid-1990s through the mid-2000s. Thus, the projected urbanization rates may be liberal, but urbanization is not totally dictated by new housing starts.

Regardless of the projections, it is quite evident that urban land is expanding and will continue to expand in the coming years, particularly in more heavily urbanized areas. Some areas are having diminished urban expansion at the core (as most of the land has been already urbanized), and the urban expansion is occurring most rapidly at the fringe around the center core. This fringe expansion is most evident in the Atlanta, Chicago, and New York areas in Figure 5, where a "doughnut hole" of edge expansion has become evident (i.e., relatively little urban land growth in the center and rapid urban growth on the edge). This pulse of expanding urbanization outward from urban cores will likely have substantial impacts on rural forest stands around urban centers. Forest management in these areas may need to adjust to address the increasingly strong impacts from urbanization (e.g., human use of forests, pollution, fire

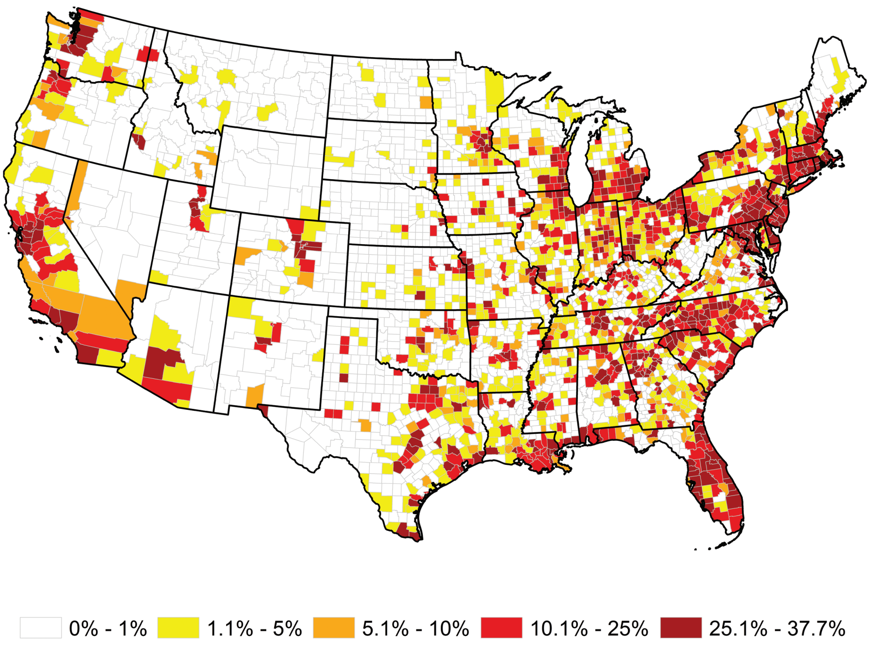

**Figure 5. Growth in percent urban land by county (2010–2060).**

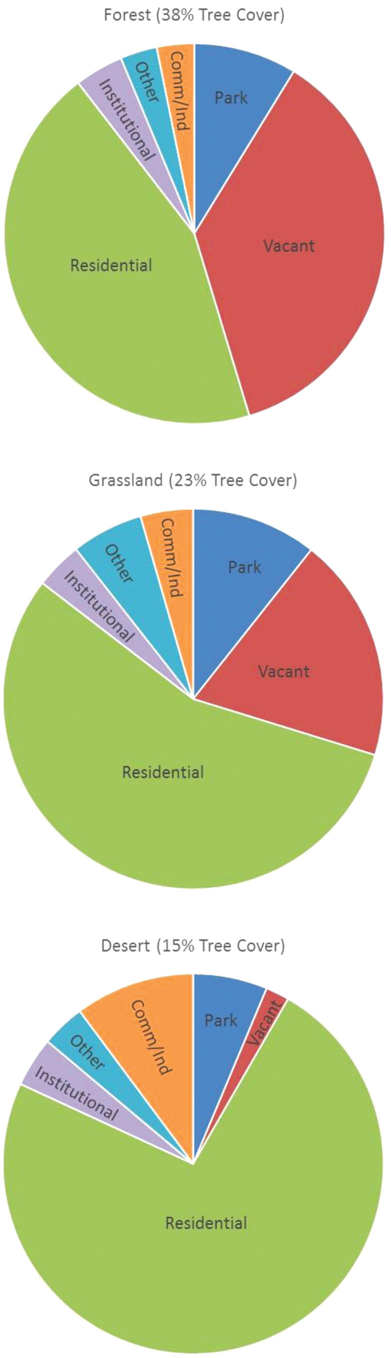

**Figure 6. Distribution of tree cover among land uses within cities based on ecoregion (Nowak et al. 1996). Comm/Ind = commercial / industrial.**

risk, invasive species, spread of insects and diseases).

## US Urban Forest Structure and Structural Values

Based on data from circa 2005, overall tree cover in the conterminous United States averaged 34.2 percent, with tree cover in urban areas averaging 35.0 percent, tree cover in urban/community areas averaging 35.8 percent, and tree cover in rural areas averaging 34.1 percent (Nowak and Greenfield 2012). To update the tree cover estimate in urban and urban/community areas, 1,000 random points were photo-interpreted in urban/community areas in each state using Google Earth imagery. The points within the urban/community areas and within just urban areas were analyzed using methods detailed in Nowak and Greenfield (2012) to determine total tree cover. The year of analysis among various Google images was recorded and chosen to be as recent as possible with interpretable imagery (cloud-free, sub-meter resolution). The average year of analysis was 2014, but imagery dates varied within the states and average dates ranged between 2012 and 2015 among the states (Table 2).

Overall urban tree cover in the United States circa 2014 averaged 39.4% of the total land area (Table 1), with tree cover in urban/community areas averaging 42.2% (Table 2). Tree cover varies by state, with urban tree cover highest in Connecticut (61.6%), Georgia (58.8%), Maine (58.5%), Massachusetts (57.1%), and New Hampshire (56.3%); and lowest in North Dakota (10.1%), Wyoming (11.9%), Nevada (12.9%), Idaho (13.1%), and Utah (14.9%). The apparent increase in urban tree cover between 2005 (35%) and 2014 (39%) is partially due to the expansion of urban land between 2000 and 2010 into rural areas (i.e., the assessments were based on different urban land areas). Because most urban areas are within forested regions, the expansion of urban land will likely increase overall tree cover, as it can consume formerly rural lands with existing tree cover. An assessment of recent urban tree cover change within 2010 urban and urban/community areas is currently underway to determine how tree cover has been changing within the current urban and urban/community areas.

Urban tree cover varies by ecoregion, with percent tree cover in urban areas negatively correlated with urban population density (Nowak and Greenfield 2012). About 75% of the tree cover in cities is found on residential and vacant lands, but the distribution varies by ecoregion (Nowak et al. 1996). In forested regions, residential areas account for 43% of total tree cover, while vacant areas account for 37%. In grasslands, the distribution shifts to 54% on residential and 20% on vacant land. In deserts, residential lands dominate tree cover with 72% of the total city tree cover on residential lands and 2% on vacant land (Figure 6). This cover distribution by ecoregion illustrates the role of ample precipitation and natural regeneration impacts on urban tree cover in forested regions.

**Table 4. Average values per acre of urban tree cover based on field samples from 34 US cities and urban areas within the conterminous United States.**

| Metric | Units | *N* | SE |
|---|---|---|---|
| Trees* | #/ac | 207 | 43 |
| Leaf area index (LAI) | ac/ac | 4.8 | 1.0 |
| Leaf biomass (d.w.) | t/ac | 1.7 | 0.3 |
| Carbon storage | t/ac | 34.3 | 6.1 |
| Carbon sequestration | t/ac | 1.2 | 0.2 |

* Woody plants with a minimum diameter at breast height (4.5 feet above ground) of one inch.
t – tons; d.w. – dry weight; ac – acre

Tree cover from natural regeneration in vacant lands has a more substantial influence on overall tree cover, as water availability increases from desert to grassland to forest regions. Similarly, the overall influence of residential areas on total tree cover increases as water availability decreases from forest to desert regions, as people often need to supply water to sustain tree cover in desert and grassland regions (Nowak et al. 1996).

In US cities, about one in three trees are planted. Land uses with the highest proportion of trees planted are residential (74.8% of trees planted) and commercial/industrial lands (61.2%). The percentage of the tree population planted is greater in cities developed in grassland areas as compared to cities developed in forests and tends to increase with increased population density and percent impervious cover in cities (Nowak 2012).

To estimate urban forest structural attributes (i.e., number of trees, leaf area, and leaf biomass), tree cover data were combined with average structural attributes per acre of urban tree cover (Table 4). These standardized values per acre of tree cover were derived from field data collected in 28 US cities and urban areas within six states from across the United States (Nowak et al. 2013). These data were based on random samples of field plots in each city or state and analyzed using the i-Tree Eco model (www.itreetools.org; Nowak et al. 2008). The number of trees were directly measured in the field, while leaf area and leaf biomass were estimated using measured tree data, allometric equations, and leaf area to biomass conversion factors (Nowak 1996, Nowak et al. 2008).

Overall, there are an estimated 5.5 billion urban trees in the United States, which equates to 22.2 trees per capita in urban areas (Table 5). States with the greatest estimated urban tree populations are: Florida (407 million), Georgia (372 million), California (343 million), North Carolina (320 million), and Texas (309 million urban trees). This total estimate is larger than a previous estimate of 3.8 billion urban trees (Nowak et al. 2001) due to increased urban land between 1990 and 2010 and improved estimates of urban tree cover. The estimates of number of trees by state are rudimentary estimates that can vary locally based on differences in tree sizes and densities, but provide an indication of the overall magnitude of this resource.

In comparing these rudimentary estimates (standardized estimates based on urban tree cover multiplied by average number of trees per unit tree cover) with urban forest field estimates from seven states, four states showed no statistically significant differences. The three states that had statistically significant differences were North Dakota (field estimate = 975,000 trees; standardized estimate for same area = 2.8 million trees), Wisconsin (field estimate = 131 million trees; standardized estimate for same area = 54 million trees), and Tennessee (field estimate = 284 million trees; standardized estimate for same area = 130 million trees). These states had either substantially higher tree cover estimates than the original field sample (North Dakota: 2.7% tree cover in field sample vs. 10.1% from photo-interpretation) or higher tree densities per unit tree cover than the sample average (Tennessee: 2.3x, Wisconsin: 2.6x above sample average). Standardized estimates per unit tree cover help account for the variation caused by differences in the amount of tree cover among states and regions, but the national average value cannot adjust for potential state variation in estimates per unit tree cover (e.g., number of trees per acre of tree cover). More state and local urban forest field data will help improve state estimates of urban forest structure.

Total urban leaf area (one-sided) in the United States is estimated at 127 million acres, with a dry-weight leaf biomass of 44 million tons. These leaves provide numerous ecosystem services and values to humans, but also produce leaf fall that contains various chemical elements. Based on the field data from the 34 cities and states (see Nowak et al. 2013), percent deciduous leaf area in urban areas is estimated at 83%. Thus, about 37 million tons of dry-weight leaf biomass falls annually in US urban forests. Given an average chemical composition of dry-weight leaves (Daubenmire 1953, Ovington 1956, Pardo et al. 2005), the amount of chemicals contained in leaf drop each year in US urban forests equates to about 21.5 million tons of carbon, 671,000 tons of nitrogen, 362,000 tons of calcium, 290,000 tons of potassium, 73,000 tons of magnesium, 62,000 tons of phosphorus, and 54,000 tons of manganese. These chemicals are all essential elements for plant growth. How these urban leaves are distributed and disposed of in urban areas will influence carbon and nutrient cycling, water quality, and the use of fertilizers to provide essential nutrients for urban forests.

A good understanding of urban forest structure is essential to not only estimate forest benefits and values, but also to guide urban forest management plans. The influx of new trees through tree planting and natural regeneration, and the loss of trees due to various sources, constantly alters the urban forest and creates many issues that forest management must address (e.g., removal of waste wood, potential recycling of leaf litter, species selections, planting rates, maintenance costs). With expanding urbanization and growing urban populations, forest structure may change more rapidly in the future, necessitating more dynamic management plans to address this potentially rapid change within and around urban areas. Forest plans should be adaptable to the various needs of a diverse population and urban landscape to minimize costs and enhance forest health, longevity, and benefits to local residences. Utilizing natural regeneration to sustain or enhance urban forest populations could be accomplished in many naturally forested areas (e.g., via reduction in mowing) to help reduce planting and some maintenance costs. However, tree maintenance would still be required, particularly for trees in close proximity to people and/or structures, and species regeneration may not be composed of desired species (e.g., invasive or pioneer species may dominate regeneration) (e.g., Nowak, Hoehn, et al. 2016).

**Table 5. State statistics (total, standard error) regarding urban forest structural characteristics and values. States in bold are within the top five in terms of acres of urban tree cover and thus top five for the structural estimates related to tree cover (number of trees, leaf area, leaf biomass, carbon storage).**

| | Trees | | | Leaf area | | Leaf biomass | | Carbon storage | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | No. | SE | | Acres | SE | t | SE | t | SE | $ |
| State | x10$^6$ | x10$^6$ | TPC* | x10$^6$ | x10$^6$ | x10$^3$ | x10$^3$ | x10$^6$ | x10$^6$ | x10$^9$ |
| Alabama | 123.9 | 25.8 | 43.9 | 2.8 | 0.59 | 990 | 201 | 20.5 | 3.6 | 2.7 |
| Arizona | 75.4 | 15.7 | 13.1 | 1.7 | 0.36 | 603 | 122 | 12.5 | 2.2 | 1.6 |
| Arkansas | 67.2 | 14.0 | 41.0 | 1.5 | 0.32 | 536 | 109 | 11.1 | 2.0 | 1.4 |
| **California** | 343.3 | 71.5 | 9.7 | 7.9 | 1.64 | 2742 | 557 | 56.9 | 10.0 | 7.4 |
| Colorado | 35.5 | 7.4 | 8.2 | 0.8 | 0.17 | 284 | 58 | 5.9 | 1.0 | 0.8 |
| Connecticut | 148.9 | 31.0 | 47.4 | 3.4 | 0.71 | 1189 | 241 | 24.7 | 4.4 | 3.2 |
| Delaware | 18.9 | 3.9 | 25.3 | 0.4 | 0.09 | 151 | 31 | 3.1 | 0.6 | 0.4 |
| **Florida** | 406.7 | 84.7 | 23.7 | 9.3 | 1.94 | 3248 | 659 | 67.4 | 11.9 | 8.7 |
| **Georgia** | 371.9 | 77.5 | 51.1 | 8.5 | 1.78 | 2971 | 603 | 61.7 | 10.9 | 8.0 |
| Idaho | 8.7 | 1.8 | 7.8 | 0.2 | 0.04 | 69 | 14 | 1.4 | 0.3 | 0.2 |
| Illinois | 164.0 | 34.2 | 14.4 | 3.8 | 0.78 | 1310 | 266 | 27.2 | 4.8 | 3.5 |
| Indiana | 104.9 | 21.9 | 22.3 | 2.4 | 0.50 | 838 | 170 | 17.4 | 3.1 | 2.3 |
| Iowa | 34.3 | 7.1 | 17.6 | 0.8 | 0.16 | 274 | 56 | 5.7 | 1.0 | 0.7 |
| Kansas | 44.8 | 9.3 | 21.1 | 1.0 | 0.21 | 358 | 73 | 7.4 | 1.3 | 1.0 |
| Kentucky | 66.6 | 13.9 | 26.3 | 1.5 | 0.32 | 532 | 108 | 11.0 | 1.9 | 1.4 |
| Louisiana | 116.3 | 24.2 | 35.1 | 2.7 | 0.56 | 929 | 189 | 19.3 | 3.4 | 2.5 |
| Maine | 27.8 | 5.8 | 54.1 | 0.6 | 0.13 | 222 | 45 | 4.6 | 0.8 | 0.6 |
| Maryland | 138.6 | 28.9 | 27.5 | 3.2 | 0.66 | 1107 | 225 | 23.0 | 4.1 | 3.0 |
| Massachusetts | 224.3 | 46.7 | 37.2 | 5.1 | 1.07 | 1792 | 364 | 37.2 | 6.6 | 4.8 |
| Michigan | 203.2 | 42.3 | 27.6 | 4.7 | 0.97 | 1623 | 329 | 33.7 | 5.9 | 4.4 |
| Minnesota | 105.6 | 22.0 | 27.2 | 2.4 | 0.50 | 843 | 171 | 17.5 | 3.1 | 2.3 |
| Mississippi | 66.9 | 13.9 | 45.6 | 1.5 | 0.32 | 534 | 108 | 11.1 | 2.0 | 1.4 |
| Missouri | 106.4 | 22.2 | 25.2 | 2.4 | 0.51 | 850 | 172 | 17.6 | 3.1 | 2.3 |
| Montana | 8.4 | 1.8 | 15.2 | 0.2 | 0.04 | 67 | 14 | 1.4 | 0.2 | 0.2 |
| Nebraska | 14.2 | 3.0 | 10.6 | 0.3 | 0.07 | 113 | 23 | 2.4 | 0.4 | 0.3 |
| Nevada | 13.1 | 2.7 | 5.1 | 0.3 | 0.06 | 105 | 21 | 2.2 | 0.4 | 0.3 |
| New Hampshire | 48.0 | 10.0 | 60.4 | 1.1 | 0.23 | 383 | 78 | 8.0 | 1.4 | 1.0 |
| New Jersey | 178.7 | 37.2 | 21.5 | 4.1 | 0.85 | 1427 | 290 | 29.6 | 5.2 | 3.8 |
| New Mexico | 18.4 | 3.8 | 11.6 | 0.4 | 0.09 | 147 | 30 | 3.1 | 0.5 | 0.4 |
| New York | 264.7 | 55.2 | 15.5 | 6.1 | 1.26 | 2114 | 429 | 43.9 | 7.7 | 5.7 |
| **North Carolina** | 319.8 | 66.6 | 50.7 | 7.3 | 1.53 | 2554 | 519 | 53.0 | 9.3 | 6.9 |
| North Dakota | 2.5 | 0.5 | 6.1 | 0.1 | 0.01 | 20 | 4 | 0.4 | 0.1 | 0.1 |
| Ohio | 220.0 | 45.8 | 24.5 | 5.0 | 1.05 | 1757 | 357 | 36.5 | 6.4 | 4.7 |
| Oklahoma | 42.1 | 8.8 | 17.0 | 1.0 | 0.20 | 336 | 68 | 7.0 | 1.2 | 0.9 |
| Oregon | 45.1 | 9.4 | 14.5 | 1.0 | 0.22 | 360 | 73 | 7.5 | 1.3 | 1.0 |
| Pennsylvania | 254.4 | 53.0 | 25.5 | 5.8 | 1.21 | 2032 | 413 | 42.2 | 7.4 | 5.5 |
| Rhode Island | 26.8 | 5.6 | 28.1 | 0.6 | 0.13 | 214 | 43 | 4.4 | 0.8 | 0.6 |
| South Carolina | 156.7 | 32.7 | 51.1 | 3.6 | 0.75 | 1252 | 254 | 26.0 | 4.6 | 3.4 |
| South Dakota | 5.6 | 1.2 | 12.1 | 0.1 | 0.03 | 44 | 9 | 0.9 | 0.2 | 0.1 |
| Tennessee | 158.1 | 32.9 | 37.5 | 3.6 | 0.75 | 1263 | 256 | 26.2 | 4.6 | 3.4 |
| **Texas** | 309.2 | 64.4 | 14.5 | 7.1 | 1.48 | 2470 | 501 | 51.3 | 9.0 | 6.6 |
| Utah | 18.0 | 3.7 | 7.2 | 0.4 | 0.09 | 144 | 29 | 3.0 | 0.5 | 0.4 |
| Vermont | 10.2 | 2.1 | 41.8 | 0.2 | 0.05 | 81 | 16 | 1.7 | 0.3 | 0.2 |
| Virginia | 159.8 | 33.3 | 26.4 | 3.7 | 0.76 | 1276 | 259 | 26.5 | 4.7 | 3.4 |
| Washington | 110.6 | 23.0 | 19.6 | 2.5 | 0.53 | 883 | 179 | 18.3 | 3.2 | 2.4 |
| West Virginia | 42.2 | 8.8 | 46.8 | 1.0 | 0.20 | 337 | 68 | 7.0 | 1.2 | 0.9 |
| Wisconsin | 69.0 | 14.4 | 17.3 | 1.6 | 0.33 | 551 | 112 | 11.4 | 2.0 | 1.5 |
| Wyoming | 3.1 | 0.6 | 8.4 | 0.1 | 0.01 | 25 | 5 | 0.5 | 0.1 | 0.1 |
| US48 | 5505 | 1147 | 22.2 | 126.3 | 26.29 | 43,969 | 8926 | 912.6 | 160.9 | 118.4 |
| Alaska | 16.3 | 3.4 | 34.8 | 0.4 | 0.08 | 130 | 26 | 2.7 | 0.5 | 0.4 |
| Hawaii | 21.6 | 4.5 | 17.3 | 0.5 | 0.10 | 172 | 35 | 3.6 | 0.6 | 0.5 |
| US50 | 5543 | 1155 | 22.2 | 127.2 | 26.45 | 44,272 | 8983 | 918.9 | 162.0 | 119.2 |

* Trees per capita in urban areas.

t – tons; SE – standard error; US48 – conterminous US, US50 – entire US

## US Urban Forest Annual Ecosystem Services and Values

The US urban forest structure provides numerous positive and negative ecosystem services and values annually, only a few of which have been quantified nationally: air pollution removal, carbon sequestration, altered building energy use, and consequent change in fuel-based (e.g., power plant) pollutant emissions.

### Air Pollution Removal

Trees remove air pollution by the interception of particulate matter on plant surfaces and the absorption of gaseous pollutants through the leaf stomata. Total pollution

**Table 6. State statistics regarding annual urban forest ecosystem service characteristics and values. Bold numbers indicate that the state is within the top five highest values for that category.**

| | Carbon sequestration | | | | Air pollution removal | | Avoided energy use | | Avoided emissions | | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | t/year | SE | $/year | SE | t/year | $/year | $/year | SE | $/year | SE | $/year |
| State | x10$^3$ | x10$^3$ | x10$^6$ | x10$^6$ | x10$^3$ | x10$^6$ | x10$^6$ | x10$^6$ | x10$^6$ | x10$^6$ | x10$^6$ |
| Alabama | 915.9 | 147.6 | 118.8 | 19.1 | 16.5 | 82.9 | 49.7 | 3.7 | 27.4 | 2.0 | 278.9 |
| Arizona | 575.9 | 92.8 | 74.7 | 12.0 | 10.5 | 33.1 | 102.2 | 4.4 | 29.9 | 1.3 | 239.9 |
| Arkansas | 478.5 | 77.1 | 62.1 | 10.0 | 8.3 | 40.4 | 34.4 | 2.5 | 18.3 | 1.3 | 155.2 |
| California | **2880.2** | 464.1 | **373.6** | 60.2 | **63.4** | **639.4** | 274.1 | 13.2 | 67.1 | 3.2 | **1354.2** |
| Colorado | 151.0 | 24.3 | 19.6 | 3.2 | 2.2 | 5.1 | 10.3 | 1.1 | 5.2 | 0.5 | 40.2 |
| Connecticut | 766.8 | 123.6 | 99.5 | 16.0 | 15.9 | 94.8 | 117.3 | 6.9 | 22.0 | 1.3 | 333.6 |
| Delaware | 136.3 | 22.0 | 17.7 | 2.8 | 2.7 | 14.6 | 43.7 | 3.4 | 29.7 | 2.3 | 105.7 |
| Florida | **4163.5** | 670.9 | **540.1** | 87.0 | **80.7** | **554.4** | **512.7** | 30.7 | **272.0** | 16.3 | **1879.2** |
| Georgia | **2832.6** | 456.5 | **367.5** | 59.2 | **62.2** | 255.6 | 124.6 | 8.8 | 92.5 | 6.5 | 840.1 |
| Idaho | 34.3 | 5.5 | 4.4 | 0.7 | 1.5 | 18.8 | 22.0 | 0.8 | 5.9 | 0.2 | 51.1 |
| Illinois | 999.7 | 161.1 | 129.7 | 20.9 | 14.6 | 157.7 | 281.4 | 8.8 | 147.2 | 4.6 | 716.0 |
| Indiana | 566.0 | 91.2 | 73.4 | 11.8 | 13.0 | 88.7 | 156.6 | 9.7 | 113.6 | 7.1 | 432.3 |
| Iowa | 177.3 | 28.6 | 23.0 | 3.7 | 2.6 | 21.0 | 59.8 | 4.9 | 53.1 | 4.4 | 156.9 |
| Kansas | 272.7 | 43.9 | 35.4 | 5.7 | 2.8 | 14.5 | 121.3 | 5.1 | 60.7 | 2.6 | 231.8 |
| Kentucky | 410.4 | 66.1 | 53.2 | 8.6 | 10.0 | 55.8 | 113.5 | 9.6 | 85.2 | 7.2 | 307.7 |
| Louisiana | 994.9 | 160.3 | 129.1 | 20.8 | 23.9 | 117.7 | 139.9 | 9.3 | 81.1 | 5.4 | 467.7 |
| Maine | 132.4 | 21.3 | 17.2 | 2.8 | 4.3 | 25.1 | 13.5 | 2.9 | 5.6 | 1.2 | 61.4 |
| Maryland | 963.4 | 155.2 | 125.0 | 20.1 | 29.2 | 177.1 | 230.2 | 14.1 | **188.0** | 11.5 | 720.3 |
| Massachusetts | 1229.2 | 198.1 | 159.5 | 25.7 | 29.5 | 197.1 | 192.2 | 10.6 | 64.7 | 3.6 | 613.5 |
| Michigan | 961.5 | 154.9 | 124.7 | 20.1 | 29.5 | 131.5 | 233.0 | 13.4 | **147.8** | 8.5 | 637.0 |
| Minnesota | 520.6 | 83.9 | 67.5 | 10.9 | 7.7 | 40.0 | 65.0 | 8.9 | 38.8 | 5.3 | 211.3 |
| Mississippi | 496.6 | 80.0 | 64.4 | 10.4 | 12.8 | 66.8 | 39.1 | 1.6 | 22.6 | 1.0 | 192.8 |
| Missouri | 654.4 | 105.4 | 84.9 | 13.7 | 14.4 | 88.3 | 174.5 | 10.1 | 105.7 | 6.1 | 453.3 |
| Montana | 33.4 | 5.4 | 4.3 | 0.7 | 1.3 | 13.3 | 2.0 | 0.4 | 1.6 | 0.3 | 21.2 |
| Nebraska | 72.8 | 11.7 | 9.4 | 1.5 | 0.6 | 4.2 | 34.7 | 1.2 | 25.4 | 0.9 | 73.7 |
| Nevada | 58.3 | 9.4 | 7.6 | 1.2 | 2.0 | 8.8 | 21.9 | 0.6 | 5.4 | 0.2 | 43.6 |
| New Hampshire | 224.7 | 36.2 | 29.2 | 4.7 | 5.7 | 15.2 | 14.5 | 1.8 | 4.5 | 0.6 | 63.4 |
| New Jersey | 1130.2 | 182.1 | 146.6 | 23.6 | 22.0 | 151.4 | 219.8 | 10.0 | 57.0 | 2.6 | 574.8 |
| New Mexico | 104.3 | 16.8 | 13.5 | 2.2 | 3.3 | 6.0 | 20.0 | 1.0 | 10.5 | 0.5 | 50.1 |
| New York | 1371.6 | 221.0 | 177.9 | 28.7 | **41.5** | **408.2** | **345.8** | 21.0 | 69.5 | 4.2 | **1001.4** |
| North Carolina | **2146.9** | 346.0 | **278.5** | 44.9 | **50.3** | 191.8 | 150.3 | 9.5 | 86.3 | 5.5 | 706.9 |
| North Dakota | 11.9 | 1.9 | 1.5 | 0.2 | 0.1 | 0.5 | 2.8 | 0.2 | 2.5 | 0.2 | 7.3 |
| Ohio | 1173.7 | 189.1 | 152.3 | 24.5 | 35.0 | **265.6** | **313.3** | 18.3 | **240.3** | 14.0 | **971.5** |
| Oklahoma | 301.3 | 48.6 | 39.1 | 6.3 | 5.5 | 34.6 | 17.8 | 2.5 | 9.9 | 1.4 | 101.5 |
| Oregon | 234.9 | 37.8 | 30.5 | 4.9 | 4.3 | 79.1 | 21.4 | 1.7 | 5.1 | 0.4 | 136.1 |
| Pennsylvania | 1337.3 | 215.5 | 173.5 | 28.0 | 40.6 | **441.6** | **290.2** | 18.7 | **164.3** | 10.6 | **1069.6** |
| Rhode Island | 149.1 | 24.0 | 19.3 | 3.1 | 3.0 | 26.1 | 37.2 | 2.2 | 5.1 | 0.3 | 87.8 |
| South Carolina | 1140.4 | 183.8 | 147.9 | 23.8 | 27.6 | 125.3 | 76.4 | 4.2 | 35.9 | 2.0 | 385.6 |
| South Dakota | 28.3 | 4.6 | 3.7 | 0.6 | 0.2 | 1.7 | 6.2 | 0.3 | 5.1 | 0.3 | 16.7 |
| Tennessee | 1033.4 | 166.5 | 134.1 | 21.6 | 23.1 | 108.2 | 83.7 | 5.8 | 50.8 | 3.5 | 376.7 |
| Texas | **2453.1** | 395.3 | **318.2** | 51.3 | 33.7 | 185.6 | **308.4** | 11.2 | 125.5 | 4.6 | 937.8 |
| Utah | 83.3 | 13.4 | 10.8 | 1.7 | 2.6 | 11.4 | 19.6 | 1.2 | 11.7 | 0.7 | 53.5 |
| Vermont | 46.7 | 7.5 | 6.1 | 1.0 | 1.1 | 5.7 | 8.2 | 1.3 | 0.5 | 0.1 | 20.4 |
| Virginia | 1007.7 | 162.4 | 130.7 | 21.1 | 30.6 | 134.7 | 114.4 | 5.2 | 69.3 | 3.1 | 449.2 |
| Washington | 614.5 | 99.0 | 79.7 | 12.8 | 16.4 | 180.3 | 56.2 | 3.8 | 11.9 | 0.8 | 328.2 |
| West Virginia | 218.7 | 35.2 | 28.4 | 4.6 | 5.3 | 30.6 | 21.4 | 2.0 | 15.6 | 1.5 | 95.9 |
| Wisconsin | 334.1 | 53.8 | 43.3 | 7.0 | 7.4 | 45.3 | 81.5 | 7.8 | 44.8 | 4.3 | 214.9 |
| Wyoming | 12.0 | 1.9 | 1.6 | 0.3 | 0.5 | 2.5 | 1.3 | 0.1 | 1.1 | 0.1 | 6.4 |
| US48 | 36,653 | 5325 | 4755 | 690.7 | 821.7 | 5398 | 5380 | 61.7 | 2743 | 33.6 | 18,274 |
| Alaska | 59.3 | 9.6 | 7.7 | 1.2 | na | na | na | na | na | na | na |
| Hawaii | 270.4 | 43.6 | 35.1 | 5.7 | na | na | na | na | na | na | na |
| US50 | 36,983 | 5361 | 4798 | 695.5 | na | na | na | na | na | na | na |

t tons; SE – standard error, US48 – conterminous US, US50 – entire US, *na* – not analyzed

removal by urban forests in the conterminous United States using updated 2014 tree cover estimates (Table 1) and 2010 pollutant conditions is 822,000 tons per year, with an annual value of $5.4 billion dollars (Table 6). The dollar value estimates are based on health care expenses (i.e., cost of illness and willingness to pay to avoid illness), productivity losses associated with specific adverse health events, and the value of a statistical life in the case of mortality as derived from the US EPA BenMAP model (Nowak et al. 2014, Abt Associates 2010). States with greatest pollution removal values by urban forests were: California ($639 million/yr), Florida ($554 million/yr), Pennsylvania ($441 million/yr), New York ($408 million/yr), and Ohio ($266 million/yr). This new national estimate is higher than a previous estimate of 717,000 tons ($4.7 billion)

(Nowak et al. 2014), due to increased tree cover. Pollution removal was greatest for ozone (660,000 tons/yr), followed by nitrogen dioxide (86,000 t/yr), sulfur dioxide (42,000 t/yr), and particulate matter less than 2.5 microns (33,000 t/yr). Health impacts include the avoidance of 670 incidences of human mortality and 575,000 incidences of acute respiratory symptoms, among other health impacts (Nowak et al. 2014). Values vary among states based on amount of tree cover, pollution concentrations, meteorological variables, and human population distribution. Values tend to increase as population density increases due to more people receiving the pollution removal benefits.

This type of analysis focuses on pollution removal effects in general, but does not address the variation in fine-scale effects of trees on pollution concentration. At the local scale, pollution concentrations can be increased if trees trap pollutants beneath tree canopies near emission sources, limit dispersion, or lower mixing heights (e.g., Nowak et al. 2006, Gromke and Ruck 2009, Wania et al. 2012, Salmond et al. 2013), but trees can also reduce pollutant concentrations in nearby homes (Maher et al. 2013). Large stands of trees can also reduce pollutant concentrations in the interior of the stand due to increased distance from emission sources and increased dry deposition (e.g., Cavanagh et al. 2009). Thus, local-scale design of trees and forests can affect local-scale pollutant concentrations. These estimates also do not address the issue of advection, where pollution removal in rural areas surrounding urban areas could lower the pollution concentrations arriving into urban areas (or vice versa). As many pollutants are generated locally, this may not be a major factor, but for some pollutants such as ozone, the reduction of pollutants in rural areas could have an impact on urban pollutant concentrations (Nowak et al. 2014). The magnitude of this potential impact is unknown and warrants further investigation.

## Carbon Sequestration and Storage

Carbon sequestration and storage estimates are based on methods in Nowak et al. (2013) and updated using more recent urban land estimates (2010), tree cover estimates (2014), and carbon values (2015). Annual gross carbon sequestration by urban forests in the conterminous United States is estimated at 36.7 million tons, with an estimated value of $4.8 billion (Table 6). This estimate is higher than the previous estimate of 27.9 million tons of carbon ($2.0 billion) (Nowak et al. 2013) due to increased urban land between 2000 and 2010, increased tree cover, and the increased social cost of carbon between 2010 ($71.2 per ton of carbon in 2007 dollars; Interagency Working Group 2010) and 2015 ($129.8 per ton of carbon in 2011 dollars; US EPA 2013, Interagency Working Group 2015). States with the greatest estimated carbon sequestration by urban forests are: Florida (4.2 million tons of carbon/yr), California (2.9 million tC/yr), Georgia (2.8 million tC/yr), Texas (2.5 million tC/yr), and North Carolina (2.1 million tC/yr) (Table 6). This sequestration annually adds to the carbon storage amount and value as trees accumulate more biomass.

Past carbon sequestration is evident in current carbon storage. Carbon storage by urban forests in the conterminous United States is estimated at 919 million tons, with an estimated value of $119 billion (Table 5). This estimate is higher than the previous estimate of 709 million tons of carbon ($50.5 billion) (Nowak et al. 2013). States with the greatest estimated carbon storage by urban forests are: Florida (67.4 million tons of carbon), Georgia (61.7 million tC), California (56.9 million tC), North Carolina (53.0 million tC), and Texas (51.3 million tC) (Table 5). Loss of urban forests will diminish both the annual sequestration and storage values through less biomass accumulation by trees and the conversion of stored carbon back to atmospheric carbon via decomposition and burning (e.g., Nowak et al. 2002).

Given the potential available space (pervious land) in urban areas, carbon storage could increase in these areas. However, given the limitations to tree growth and establishment in urban areas imposed by humans (e.g., mowing) and nature (e.g., lack of precipitation), increasing carbon storage in urban areas is not likely without a major effort to change current conditions (both social and physical). Long-term monitoring of urban forests is needed to better understand rates of changes in urban areas and provide better estimates of long-term carbon trends. In addition to understanding change in carbon stocks, urban tree management practices need to be considered when estimating the net effects of urban trees on atmospheric carbon dioxide, as various maintenance activities emit carbon back to the atmosphere via fossil-fuel combustion (e.g., from chainsaws, trucks, chippers) (Nowak et al. 2002). As urban areas produce substantial emissions of carbon, tree effects on carbon emissions through altering of microclimates, energy use, and maintenance emissions need to be incorporated with tree storage and sequestration estimates to develop a more complete assessment of the role of urban forests on climate change (Nowak et al. 2013).

## Building Energy Use and Avoided Emissions

Urban trees and forests alter building energy use and associated emissions from power plants by shading buildings, cooling air temperatures, and altering wind speeds around buildings. Based on updated tree cover (Table 1), urban forests in the conterminous United States annually reduce residential building energy use to heat and cool buildings by $5.4 billion per year (based on state utility costs). They also avoid the emission of thousands of tons of pollutants (carbon dioxide, nitrogen oxides, sulfur dioxide, methane, carbon monoxide, particulate matter less than 2.5 and 10 microns, and volatile organic compounds [VOC]) valued at $2.7 billion per year (based on social costs and externality values; see Nowak et al. 2017) (Table 6). States with the greatest energy savings were: Florida ($513 million/yr), New York ($346 million/yr), Ohio ($313 million/yr), Texas ($308 million/yr), and Pennsylvania ($290 million/yr). States with the greatest value in reduced emissions were: Florida ($272 million/yr), Ohio ($240 million/yr), Maryland ($188 million/yr), Pennsylvania ($164 million/yr), and Michigan ($148 million/yr). Due to updated tree cover values, the national estimate is higher than a previous estimate of $4.7 billion for energy conservation and $2.3 billion from avoided emissions (Nowak et al. 2017). Energy savings and reduced emission values among states vary based on differences in the amount of tree cover, local climate, building vintages, energy costs, and fuels used to produce energy. Specific designs to reduce energy use with urban trees could increase these values and further reduce energy use and improve air quality in the United States.

The total value of the four services (pollution removal, carbon sequestration, avoided building energy use, and avoided emissions) is $18.3 billion annually, or $687 per acre of urban tree cover (Table 6). The values were greatest in: Florida ($1.9 billion/yr), California ($1.4 billion/yr), Pennsylvania ($1.1 billion/yr), New York ($1.0 billion/yr), and Ohio ($971 million/yr). These service values are conservative, as many ecosystem services are not valued (e.g., effects of urban forests on air temperatures, water quality and flooding, wildlife, aesthetics, and social well-being). These estimates also do not include various direct (e.g., tree planting, maintenance, removals) and indirect (e.g., pollen, VOC emission impacts on ozone formation) costs associated with urban forests. These costs will subtract from the limited current gross value estimate of $18.3 billion per year, yet other non-quantified benefits would add to this value. Further research is needed to adequately quantify these numerous other benefits and costs associated with urban forests.

## Discussion

Although decadal growth rates of urban land decreased slightly between the 1990s and 2000s, urban land growth is still projected to be substantial in the coming decades. Urban land is projected to more than double between 2010 and 2060, which will impact forest and agricultural lands, as well as expand the importance of urban forests in relation to environmental quality and human well-being. As urban land expands, it subsumes formerly rural lands. In the 1990s, about one-third of new urban land came from forests and one-third from agricultural lands (Nowak et al. 2005). Between 2000 and 2010, 36.2% of new urban land came from developed land, 22.7% from agricultural land, and 21.0% from forest land (US Forest Service 2016a). This subsuming of rural land has implications not only for urban areas, but also for forest and agricultural management as human populations develop rural land and move in close proximity to forests and farms. Forest management effects include issues associated with fires at the expanding urban wildland interface, exotic pest introductions and infestations, unmanaged outdoor recreation, and forest fragmentation concerns associated with forests within or near urban areas (Nowak et al. 2005). The issue of urban expansion is of particular concern in the Southeast because the states with greatest urban expansion between 2000 and 2010 occurred in this region and most of the urban expansion in some of these states (i.e., Georgia, North Carolina, and South Carolina) occurs in forested areas.

As the urban population expands and becomes more intermixed across the landscape, urban forests will become increasingly important to sustain human health and well-being, as well as environmental quality in both urban and rural areas. Urban forests currently produce billions of dollars in annual benefits associated with air quality, climate change, and reduced energy use. Planning and managing urban forests to sustain forest health and maximize these environmental benefits, as well as numerous other benefits not addressed in this paper, will produce more environmental benefits and values, particularly considering the continued expansion of urban areas. Efforts to minimize urban growth, particularly within forested areas, can also help sustain the numerous ecosystem services provided by intact forest stands. When designing urban forests to maximize benefits, local scale issues need to be considered (e.g., trees' impacts on local air pollution concentration). Trade-offs between various costs and services need to be considered in urban forest management to optimize local benefits.

The estimates given in this paper, exclusive of estimates of existing urban land and tree cover, are first-order approximations and have various limitations that are detailed in the associated methods papers (Nowak et al. 2013, 2014, 2017). Future research and continued data collection are needed to improve and expand estimates on urban forest structure and ecosystem services and values. To improve state estimates, more urban forest data are needed, as various structural attributes and ecosystem services will vary from mean-based estimates as tree sizes and densities vary from the national mean. Our knowledge of urban forests is expanding as more field data are collected on trees in urban areas, but the data nationally are still limited. To overcome this limitation, urban forest data are being collected by local constituents and analyzed using i-Tree software. In addition, the US Forest Service Forest Inventory and Analysis program has started to implement, in partnership with cities, long-term urban forest monitoring. This program measures urban forest data annually to assess urban forest structure, ecosystem services and values, and changes in structure, services, and values through time. The first city to have a completed a baseline inventory was Austin, TX (Nowak, Bodine, et al. 2016), with 25 cities to be monitored in 2017 and new cities to be added to the monitoring program in the next few years (US Forest Service 2016b).

Urban forest monitoring, along with continued research related to urban forest structure, change, benefits, and costs, will be essential to providing better information to guide management and policies. Research to improve estimates in this paper could focus on: a) adding new ecosystem services, values and costs to provide a more comprehensive assessment, b) refining estimates of services and values per unit tree cover to develop more local or regional standardized values based on increased field measurements from across the nation, c) continued assessments of urban and community land and monitoring of trees and tree cover within these areas to better understand urban forest change, and d) separating out changes within existing urban/community areas from changes due to the incorporation of formerly rural lands. This separation will lead to a better understanding of how urban expansion is affecting overall tree cover and benefits versus how forests are changing within existing urban/community areas.

By measuring and monitoring urban forests, society can better understand the magnitude of the resource, the values provided by urban forests, and how urban forests and associated values are changing through time. The development of management plans to create desirable, healthy, and sustainable urban forests can help ensure that these forests continue to improve environmental quality and human health and well-being for current and future generations.

## Conclusion

Urban areas in the United States continue to expand, increasing the importance of urban forests in sustaining environmental quality and human health and well-being nationally. Urban forests currently provide substantial value nationally. However, only a few ecosystem services have been evaluated and more services and costs remain to be quantified. The urban expansion along with the values associated with urban forests indicate that urbanization and urban forests are likely to be one of the most important forest influences and influential forests of the 21st century. Through proper planning and management, urban forest health can be sustained and environmental and human health values improved. A healthy urban forest and proper urban forest management can help reduce some of the environmental issues associated with urbanization (e.g., increased air temperatures and energy use, reduced air and water quality, increased human stress) and ultimately help humans living within and around urban areas. Information in this paper provides an estimate of the magnitude and variation of the urban forest resource nationally, its likely expansion in the future, and the value of just a few of its ecosystem services. Additional information from urban forest inventories planned and in progress now will continue to improve these estimates. This information can be used to help guide state and national policies to manage, protect, and enhance this valuable resource.

## Literature Cited

Abt Associates. 2010. *BenMAP Environmental Benefits Mapping and Analysis Program*. Office of Air Quality Planning and Standards, US Environmental Protection Agency, Research Triangle Park, NC, 283 p. Available online at http://www.epa.gov/airquality/benmap/models/BenMAPManualAugust2010.pdf; last accessed May 24, 2012.

Angel, S., J. Parent, D.L. Civco, A. Blei, and D. Potere. 2011. The dimensions of global urban expansion: Estimates and projections for all countries, 2000–2050. *Prog. Plann.* 75:53–107.

Cavanagh, J.E., P. Zawar-Reza, and J.G. Wilson. 2009. Spatial attenuation of ambient particulate matter air pollution within an urbanised native forest patch. *Urban For. Urban Green.* 8:21–30.

Daubenmire, R. 1953. Nutrient content of leaf litter of trees in the Northern Rocky Mountains. *Ecology*. 34(4):786–793.

Dobbs, C., M.J. Martinez-Harms, and D. Kendal. 2017. Ecosystem services. Ch. 4, p. 51–64, in *Routledge handbook of urban forestry*, Ferrini, F., C.C. Konijnendijk, and A. Fini (eds.). Routledge, New York.

Dwyer, J.F., E.G. McPherson, H.W. Schroeder, and R.A. Rowntree. 1992. Assessing the benefits and costs of the urban forest. *J. Arboric.* 18(5):227–234.

Gromke, C., and B. Ruck. 2009. On the impact of trees on dispersion processes of traffic emissions in street canyons. *Boundary-Layer Meteorol.* 131(1):19–34.

Interagency Working Group on Social Cost of Carbon, US Government. 2010. *Technical support document: Social cost of carbon for regulatory impact analysis under Executive Order 12866*. Available online at http://www.epa.gov/oms/climate/regulations/scc-tsd.pdf; last accessed June 13, 2012.

Interagency Working Group on Social Cost of Carbon, US Government. 2015. *Technical support document: Social cost of carbon for regulatory impact analysis under Executive Order 12866*. Available online at https://www.whitehouse.gov/sites/default/files/omb/inforeg/scc-tsd-final-july-2015.pdf; last accessed Jan. 19, 2017.

Lyytimaki, J. 2017. Disservices of urban trees. Chapter 12, p. 164–176, in *Routledge handbook of urban forestry*, Ferrini, F., C.C. Konijnendijk, and A. Fini (eds.). Routledge, New York.

Maher, B.A., I.A.M. Ahmed, B. Davison, V. Karloukovski, and R. Clarke. 2013. Impact of roadside tree lines on indoor concentrations of traffic-derived particulate matter. *Environ. Sci. Technol.* 47(23):13737–13744.

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. 2012. Contrasting natural regeneration and tree planting in 14 North American cities. *Urban For. Urban Green.* 11:374–382.

Nowak, D.J. 2017. Assessing the benefits and economic values of trees. Chapter 11, p. 152–163, in *Routledge handbook of urban forestry*, Ferrini, F., C.C. Konijnendijk, and A. Fini (eds.). Routledge, New York.

Nowak, D.J., N. Appleton, A. Ellis, and E. Greenfield. 2017. Residential building energy conservation and avoided power plant emissions by urban and community trees in the United States. *Urban For. Urban Green.* 21:158–165.

Nowak, D.J., A.R. Bodine, R.E. Hoehn, et al. 2016. *Austin's Urban Forest, 2014*. USDA Forest Service, Northern Research Station Resources Bulletin, NRS-100. Newtown Square, PA. 55 p.

Nowak, D.J., D.E. Crane, and J.C. Stevens. 2006. Air pollution removal by urban trees and shrubs in the United States. *Urban For. Urban Green.* 4:115–123.

Nowak, D.J., and J.F. Dwyer. 2007. Understanding the benefits and costs of urban forest ecosystems. P. 25–46 in *Urban and community forestry in the Northeast*, Kuser, J. (ed.). Springer, New York.

Nowak, D.J., and E.J. Greenfield. 2012. Tree and impervious cover change in U.S. cities. *Urban For. Urban Green.* 11:21–30.

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. *Environ. Pollut.* 178:229–236.

Nowak, D.J., S. Hirabayashi, A. Ellis, and E.J. Greenfield. 2014. Tree and forest effects on air quality and human health in the United States. *Environ. Pollut.* 193:119–129.

Nowak, D.J., R.E. Hoehn, A.R. Bodine, E.J. Greenfield, and J. O'Neil-Dunne. 2016. Urban forest structure, ecosystem services and change in Syracuse, NY. *Urban. Ecosyst.* 19:1455–1477.

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. Urban. For.* 34(6):347–358.

Nowak, D.J., M.H. Noble, S.M. Sisinni, and J.F. Dwyer. 2001. Assessing the U.S. urban forest resource. *J. Forest.* 99(3):37–42.

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. *Landsc. Urban. Plan.* 36:49–57.

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.

Nowak, D.J., and J.T. Walton. 2005. Projected urban growth and its estimated impact on the U.S. forest resource (2000–2050). *J. Forest.* 103(8):383–389.

Nowak, D.J., J.T. Walton, J.F. Dwyer, S. Myeong, and L.G. Kaya. 2005. The increasing influence of urban environments on U.S. forest management. *J. Forest.* 103(8):377–382.

Ovington, J.D. 1956. The composition of tree leaves. *Forestry*. 29(1):22–28.

Pardo, L.H., M. Robin-Abbott, N. Duarte, and E.K. Miller. 2005. Tree chemistry database (version 1.0). Available online at https://www.treesearch.fs.fed.us/pubs/9464; last accessed Jan. 19, 2017.

Roy, S., J. Byrne, and C. Pickering. 2012. A systematic quantitative review of urban tree benefits, costs, and assessment methods across cities in different climatic zones. *Urban For. Urban Green.* 11(4): 351–363.

Salmond, J.A., D.E. Williams, G. Laing, et al. 2013. The influence of vegetation on the horizontal and vertical distribution of pollutants in a street canyon. *Sci. Total. Environ.* 443:287–298.

Wania, A., M. Bruse, N. Blond, and C. Weber. 2012. Analysing the influence of different street vegetation on traffic-induced particle dispersion using microscale simulations. *J. Environ. Manage.* 94:91–101.

US Census Bureau. 2017a. *2010 Census urban and rural classification and urban area criteria*. Available online at https://www.census.gov/geo/reference/ua/urban-rural-2010.html; last accessed Mar. 22, 2017.

US Census Bureau. 2017b. *New residential construction*. Available online at https://www.census.gov/construction/nrc/historical_data/index.html; last accessed July 27, 2017.

US Environmental Protection Agency (US EPA). 2013. *Fact sheet: Social cost of carbon*. Available online at https://www3.epa.gov/climatechange/Downloads/EPAactivities/scc-fact-sheet.pdf; last accessed Jan. 19, 2017.

US Forest Service. 2016a. *Future of America's forests and rangeland*. General Technical Report WO-94. Available online at https://www.treesearch.fs.fed.us/pubs/53212; last accessed Feb. 15, 2017.

US Forest Service. 2016b. *Urban Forest Inventory and Analysis (FIA)*. Available online at http://www.fs.fed.us/research/urban/fia.php; last accessed Dec. 15, 2016.