Landscape and Urban Planning 107 (2012) 21–30

Contents lists available at SciVerse ScienceDirect

Landscape and Urban Planning

journal homepage: www.elsevier.com/locate/landurbplan

Tree and impervious cover in the United States

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A R T I C L E   I N F O

Article history:
Received 29 June 2011
Received in revised form 6 April 2012
Accepted 10 April 2012
Available online 9 May 2012

Keywords:
Urban tree cover
Rural tree cover
State tree cover
Urban impervious cover
Rural impervious cover
State impervious cover

A B S T R A C T

Using aerial photograph interpretation of circa 2005 imagery, percent tree canopy and impervious surface cover in the conterminous United States are estimated at 34.2% (standard error (SE) = 0.2%) and 2.4% (SE = 0.1%), respectively. Within urban/community areas, percent tree cover (35.1%, SE = 0.4%) is similar to the national value, but percent impervious cover is significantly higher (17.5%, SE = 0.3%). Tree cover per capita in urban areas averaged 377 m^2/person, while impervious cover per capita averaged 274 m^2/person. Percent tree cover in urban/community areas tends to be significantly higher than in rural areas in several predominantly grassland states, with the greatest difference in Kansas (+17.3%). Most states in more forested regions exhibited a decrease in tree cover between urban/community areas and rural lands, with greatest difference in Kentucky (−37.9%). These changes in tree cover varied significantly among states, illustrating the roles of urban development patterns, management/planning interactions, and the natural environment on creating cover patterns exhibited in urban areas. Understanding these forces and patterns can lead to better planning and management activities to optimize the mix of tree and impervious cover to sustain urban functions while enhancing environmental quality and human health in urban areas.

Published by Elsevier B.V.

1. Introduction

Tree canopy and impervious surface cover affect ecosystem services provided by a landscape. These cover elements play particularly important roles in cities and towns in terms of their impacts on the physical and socio-economic environment, and, consequently, human health and well-being in these areas. Trees not only provide numerous economic and ecosystem services and values to a community, but also incur various economic or environmental costs. Trees supply ecosystem services associated with air and water quality, building energy conservation, moderation of air temperatures, reductions in ultraviolet radiation, and many other environmental and social benefits (e.g., Dwyer, McPherson, Schroeder, & Rowntree, 1992; Kuo & Sullivan, 2001; Nowak & Dwyer, 2007; Westphal, 2003; Wolf, 2003). Costs associated with trees can be both economic (e.g., planting and maintenance, increased building energy costs) and environmental (e.g., pollen, volatile organic compound emissions) (Nowak & Dwyer, 2007).

Likewise, impervious cover plays an important role in the landscape, particularly in developed areas. These surfaces, such as roads, buildings, sidewalks, and parking lots, facilitate transportation and provide shelter, but also can negatively impact the environment. Increased impervious surface area can enhance local temperatures and heat islands effects (Heisler & Brazel, 2010; Oke, 1989), which consequently affects building energy use, human comfort and health, ozone production, and pollutant emissions.

Impervious surfaces impede water infiltration rates (Hamilton & Waddington, 1999; Pitt & Lantri, 2000), and reduce percolation, water table levels, and stream baseflow regimes (Faulkner, Edmonds-Brown, & Green, 2000; Lerner, 2002). Removal of forest cover and/or increased impervious area due to urbanization is known to increase stream flow and peak runoff in streams (Leopold, 1968; National Research Council, 2008). These changes in stream flows can lead to flooding, soil erosion, and sedimentation in streams (Anderson, 1970; McMahon & Cuffney, 2000; Paul & Meyer, 2001; Rose & Peters, 2001; Urbonas & Benik, 1995). As the volume of urban stormwater runoff increased throughout the United States from the increase in impervious surfaces, the quality of surface runoff has degraded substantially (U.S. EPA, 1983). Poorer water quality and increased temperatures due to impervious surfaces can significantly impact human health.

Quantifying tree and impervious cover within the United States is important for understanding the magnitude, distribution and variation of these landscape attributes nationally. By quantifying these cover attributes, better estimates of the impacts of these landscape cover elements can be ascertained, and improved landscape planning and management can be initiated. Understanding how cover types vary among states can also support the development of optimal cover recommendations to sustain natural ecosystem functions in urban areas.

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0169-2046/$ – see front matter. Published by Elsevier B.V.
http://dx.doi.org/10.1016/j.landurbplan.2012.04.005

Various estimates of tree and impervious cover in the United States have been made in the past, often based on satellite data. The most recent estimates of tree and impervious cover estimates are based on the 2001 National Land Cover Database (NLCD) that provides free, 30 m resolution, percent tree canopy and percent impervious cover values for the conterminous United States derived from circa 2001 Landsat 7 imagery (MRLC, 2010). However, NLCD estimates of tree cover tend to underestimate tree cover, relative to photo-interpretation estimates, in the conterminous United States by an average of 9.7% (SE = 1.0%) and impervious cover by 1.4% (SE = 0.4%) with underestimates varying by region (Nowak & Greenfield, 2010).

Google Earth® imagery provides a good means to assess overall cover as it offers nearly complete coverage of the conterminous United States with interpretable aerial images. The purpose of this paper is to determine the magnitude and variation in tree and impervious surface cover among states using aerial photo-interpretation, and to quantify how these cover types vary overall and within and among rural and urban/community defined areas.

2. Methods

To determine the percent tree and impervious cover in the United States, photo-interpretation of Google Earth® imagery was conducted. This interpretation was done in various stages based on the area being analyzed: (a) a sampling of the urban/community area in the conterminous United States was conducted, (b) the conterminous United States was interpreted within 65 NLCD mapping zones (Nowak & Greenfield, 2010) to determine cover in rural areas, and (c) an analysis of rural and urban/community areas in Alaska and Hawaii was conducted.

2.1. Photo-interpretation

Within each area of analysis, random points were laid and interpreted to classify the cover type of each point on the Google Earth® image. Trained photo interpreters with experience interpreting leaf-off and leaf-on imagery classified each point as trees/large shrubs (yes/no), impervious surface (yes/no), or as a non-interpretable image. As tree and impervious cover designations are not mutually exclusive (e.g., tree cover over sidewalk or road), the photo interpreters were instructed to determine if the tree canopy covered an impervious surface, in which case it was classified as both tree and impervious. Most points (99.6%), exclusive of Alaska and Hawaii, fell on images that were readily interpretable with a resolution of approximately 1 m or less. Points falling on imagery with medium to coarse resolution (e.g., 30 m resolution) or with atmospheric obstructions (clouds) were considered non-interpretable and not included in the final analysis. This relatively minor omission of points should not lead to any bias (excluding Alaska) as the non-interpretable points were scattered throughout the United States. Dates of Google Earth® imagery were circa 2005 and had varying dates.

Within each analyzed area, the percentage of tree or impervious cover (p) was calculated as the number of sample points (x) hitting the cover attribute divided by the total number of interpretable sample points (n) within the area of analysis ($p = x/n$). The standard error of the estimate (SE) was calculated as $\mathrm{SE} = \sqrt{p(1-p)/n}$ (Lindgren & McElrath, 1969). This method has been used to assess tree cover in many cities (e.g., Nowak et al., 1996).

Six photo-interpreters were used for these analyses. Photo interpretation results were verified by having a random 10% sample of the points reinterpreted by another photo-interpreter. Generally, the quality control checks resulted in high agreement with the mean percent of agreement of about 95%. Some of the disagreements in audit results were due to image changes in Google imagery between the original interpretation and the audit.

2.2. Photo-interpretation of urban/community areas

Photo-interpretation was conducted to estimate tree and impervious cover only within urban/community areas of the conterminous United States. The definition of community is based on jurisdictional or political boundaries delimited by U.S. Census Bureau definitions of incorporated or designated places (U.S. Census Bureau, 2007). Community lands are places of established human settlement that may include all, some, or no urban land within their boundaries. The definition of urban is based on population density as delimited using the U.S. Census Bureau's (2007) definition: all territory, population, and housing units located within urbanized areas or urban clusters. Urbanized area and urban cluster boundaries encompass densely settled territories, which are described by one of the following:

- one or more block groups or census blocks with a population density of at least 386.1 people/km^2 (1000 people/mi^2),
- surrounding census blocks with a minimum population density of 193.1 people/km^2 (500 people/mi^2), or
- less densely settled blocks that form enclaves or indentations, or are used to connect discontinuous areas.

As urban land reveals 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), both definitions provide information related to human settlements and the forest resources within those settlements. As some urban land exists beyond community boundaries and not all community land is urban (i.e., communities are often a mix of urban and rural land), the category of "urban/community" was created to classify the union of these two geographically overlapping definitions where most people live (Fig. 1).

Within urban/community areas in the conterminous United States, 15,000 random points were laid for photo-interpretation of tree and impervious cover. Based on GIS boundaries, each point was also classified as whether the point was within urban land, community land, or both. If the sample size in urban land or community land within each state was less than 100 points, additional points were randomly sampled to reach a minimum sample size of 100 to attain a maximum potential standard error of 5% for these areas.

Estimates of tree and impervious cover in each state were then made for: (1) urban land, (2) community land and (3) urban/community land. In total, 15,299 points were sampled in urban/community land, with 2488 total points in urban land alone, 5856 points in community land alone, and 6955 in areas where urban and community land overlapped. Tree and impervious cover in urban areas were also divided by 2000 U.S. Census urban population to estimate the tree and impervious cover per capita in urban areas in each state. Spearman correlation was used to test for relationships between urban impervious cover and urban tree cover, between urban impervious cover and urban population density, and between urban tree cover and urban population density (alpha = 0.05).

2.3. Comparison of urban/community cover with rural cover by state

Photo-interpretation of the lower 48 states was conducted as part of a project to test how well the 2001 National Land Cover Database (NLCD) tree and impervious cover maps estimated tree

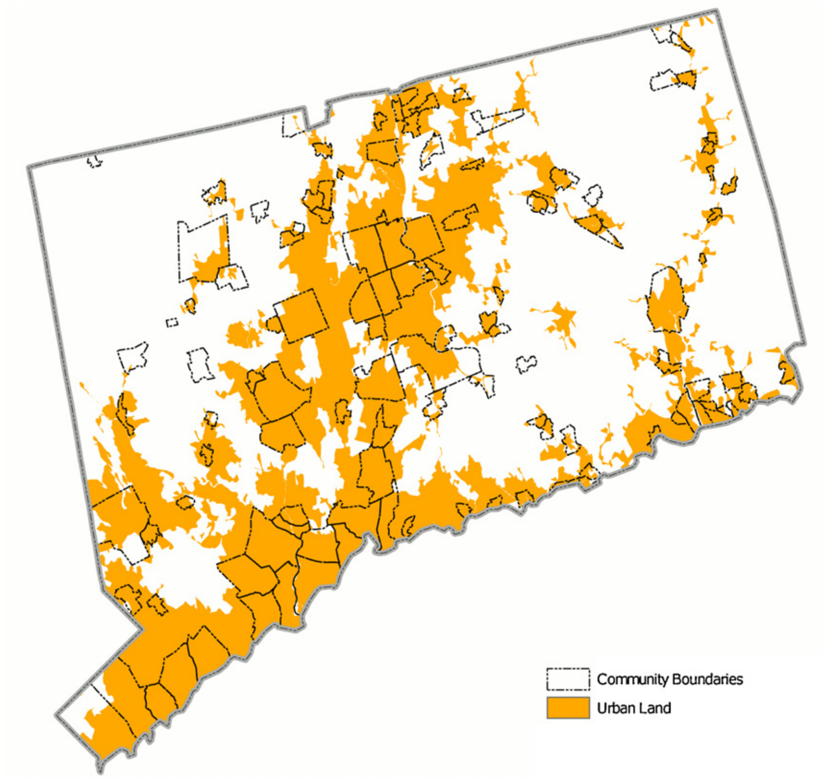

Fig. 1. Urban and community land in Connecticut (2000) (U.S. Census Bureau, 2007).

and impervious cover within 65 mapping zones that cover the conterminous United States (Nowak & Greenfield, 2010). Within each mapping zone, 1000 randomly located points were converted and transformed into a Google Earth® compatible format (Google Inc., 2011) for photo-interpretation.

After photo-interpretation of the zones was completed, state boundaries were overlaid on the points to classify each point to its associated state. Because each mapping zone has a different density of points and because parts of different mapping zones could be within a state, each point was classified as to its state/mapping zone combination (e.g., NY, zone 63) and the area of each state/mapping zone combination was calculated using Geographic Information Systems (GIS). For each state/mapping zone combination that did not have a minimum of 50 sample points, additional points were randomly added and interpreted to reach the minimum sample size of 50 points. Additional points were only added to 66 small state/mapping zone polygons to attain the minimum sample size. In total, 66,986 points were interpreted for the conterminous United States. These points were used to determine cover in rural (i.e., non-urban/community areas) areas ($n = 62{,}803$) by weighting each state/mapping zone cover estimate and standard error by its zone land area within rural land to estimate the total rural percent cover (tree and impervious) and associated standard error.

To determine tree and impervious cover for each state, rural ($n = 62{,}803$) and urban/community ($n = 15{,}299$) cover estimates and standard errors were weighted by its land area to estimate the total state percent cover (tree and impervious) and associated standard error (total $n = 78{,}102$).

Percent tree or impervious cover and its 95% confidence interval were calculated for rural land and urban/community land in each state. If the confidence intervals between rural and urban/community estimates did not overlap, then the difference between rural and urban/community tree or impervious cover was considered to be statistically significant. Spearman correlation was used to test the relationship between tree cover within urban areas and urban/community areas with overall state tree cover (alpha = 0.05).

2.4. Photo-interpretation of Alaska and Hawaii

As Alaska and Hawaii were not part of the original analyses of the conterminous United States, these states were analyzed separately. To analyze these states, 1000 random points were analyzed within urban land and a different 1000 points were analyzed in community areas. After this analysis, each point was classified as to whether it was within urban boundaries, community boundaries, and urban/community boundaries based on GIS census boundaries of these classes. Area of each class was also calculated using the GIS boundary files. Percent cover and standard error (SE) were calculated for each class and then weighted by the class area to produce a total estimate of percent cover and SE for each class type (i.e., urban, community, and urban/community).

For rural land, an additional 1000 points were interpreted. Due to poor image quality, the analysis of Alaska rural area and thus state total cover is not reported, as only 23.5% of the rural points could be interpreted. Also for Alaska, only 53.6% of the points in community land were interpretable, but these points were included in the analysis of community and urban/community cover. In Hawaii, 97.6% of the points were interpretable in urban/community areas and 98.7% in rural areas.

3. Results

Tree cover in the conterminous United States is estimated at 34.2% (SE = 0.2) or 266.7 million hectares (659.0 million acres). Urban/community areas, which occupy 5.3% of the land area, have comparable tree cover at 35.1% (SE = 0.4) or 14.6 million hectares of tree cover (36.2 million acres) (Table 1). Including Alaska and

Table 1
Summary of percent tree cover statewide, and within urban, community, urban/community (UC) and rural land.

State	Percent tree cover																% of state tree cover in UC	UC tree cover (ha)	State tree cover (ha)
	Statewide	SE	*n*	Urban	SE	*n*	Comm.	SE	*n*	UC	SE	*n*	Rural	SE	*n*	%UC[a]			
Alabama	70.0	1.5	1366	53.0	3.9	164	55.4	2.4	413	55.2	2.4	446	71.5	1.7	920	9.5	7.5	701,000	9,369,000
Arizona	19.2	0.7	3105	16.4	3.1	140	17.9	1.7	487	17.6	1.7	500	19.3	0.8	2605	5.3	4.9	277,000	5,659,000
Arkansas	57.2	1.6	1146	43.0	5.0	100	41.8	3.4	213	42.3	3.3	222	57.9	1.6	924	4.4	3.3	259,000	7,876,000
California	36.1	0.6	5835	19.9	1.5	728	26.3	1.3	1083	25.1	1.2	1237	37.1	0.6	4598	8.4	5.9	870,000	14,794,000
Colorado	23.6	0.8	2205	17.4	3.6	109	19.8	2.8	207	18.5	2.5	233	23.7	0.8	1972	2.6	2.0	130,000	6,353,000
Connecticut	72.6	2.8	298	66.5	3.6	173	66.0	4.7	100	67.4	3.4	190	75.9	4.1	108	38.8	36.0	337,000	938,000
Delaware	33.3	4.0	200	38.0	4.9	100	33.0	4.7	100	35.0	4.8	100	33.0	4.7	100	17.2	18.1	32,000	175,000
Florida	54.9	1.3	1991	35.1	2.0	553	33.9	1.9	654	35.5	1.7	829	58.4	1.5	1162	15.3	9.9	813,000	8,255,000
Georgia	66.4	1.3	1801	52.0	2.6	367	54.3	2.7	352	54.1	2.1	542	67.7	1.4	1259	9.5	7.7	781,000	10,128,000
Idaho	37.9	0.9	2127	13.0	3.4	100	12.0	3.2	100	10.0	3.0	100	38.2	1.0	2027	0.8	0.2	18,000	8,204,000
Illinois	15.6	1.1	1374	26.4	2.4	329	23.9	2.2	380	25.4	2.0	468	14.7	1.2	906	8.6	13.9	317,000	2,273,000
Indiana	25.7	1.5	1081	22.3	3.0	188	23.2	2.9	207	23.7	2.6	266	25.9	1.6	815	8.0	7.4	178,000	2,407,000
Iowa	10.4	0.9	1265	24.0	4.3	100	18.8	2.8	191	19.0	2.8	200	10.1	0.9	1065	3.6	6.6	100,000	1,511,000
Kansas	8.0	0.7	1483	28.0	4.5	100	26.5	4.4	102	25.0	4.0	116	7.7	0.7	1367	1.8	5.6	95,000	1,709,000
Kentucky	58.0	1.6	1081	26.9	4.3	104	19.6	3.2	153	22.1	3.1	181	60.0	1.7	900	5.1	1.9	117,000	6,072,000
Louisiana	51.5	2.0	906	32.2	3.8	152	35.2	3.1	236	34.9	2.9	278	52.6	2.1	628	6.2	4.2	265,000	6,313,000
Maine	83.1	1.3	834	54.0	5.0	100	51.6	4.5	122	52.3	4.4	128	84.4	1.4	706	4.0	2.5	176,000	7,016,000
Maryland	42.8	2.6	451	32.9	3.6	167	34.7	3.7	167	34.3	3.3	210	45.2	3.1	241	21.9	17.5	203,000	1,160,000
Massachusetts	70.8	2.3	472	64.5	3.0	251	60.9	3.8	161	65.1	2.7	304	74.4	3.4	168	38.6	35.5	534,000	1,507,000
Michigan	59.5	1.5	1492	34.6	2.8	289	34.0	2.9	262	35.0	2.5	377	61.4	1.6	1115	7.1	4.2	376,000	8,975,000
Minnesota	34.8	1.1	1788	31.0	3.7	158	33.8	2.4	379	34.0	2.4	400	34.9	1.1	1388	4.9	4.7	361,000	7,599,000
Mississippi	64.0	1.8	902	41.0	4.9	100	47.1	3.6	189	47.3	3.5	201	64.8	1.9	701	4.6	3.4	268,000	7,911,000
Missouri	40.3	1.4	1399	31.1	3.6	164	29.2	2.8	257	31.5	2.7	289	40.7	1.5	1110	4.6	3.6	263,000	7,272,000
Montana	27.5	0.7	3239	9.0	2.9	100	37.9	3.1	240	36.3	3.0	251	27.4	0.7	2988	2.0	2.7	279,000	10,478,000
Nebraska	3.6	0.5	1365	19.0	3.9	100	14.0	3.5	100	15.0	3.6	100	3.5	0.5	1265	1.0	4.0	29,000	714,000
Nevada	11.6	0.7	2177	12.0	3.2	100	9.5	1.8	262	9.6	1.8	271	11.6	0.8	1906	2.7	2.3	75,000	3,313,000
New Hampshire	88.9	1.8	325	64.0	4.8	100	67.0	4.7	100	66.0	4.7	100	91.5	1.9	225	10.0	7.4	158,000	2,129,000
New Jersey	57.0	2.8	409	50.4	3.2	240	51.9	3.7	183	53.3	2.9	287	59.8	4.4	122	42.1	39.4	452,000	1,149,000
New Mexico	19.1	0.7	2576	12.0	3.2	100	12.9	2.6	163	12.0	2.5	175	19.2	0.7	2401	1.7	1.1	63,000	6,000,000
New York	65.0	1.1	1923	41.2	2.6	347	41.1	2.5	375	42.6	2.2	500	67.6	1.2	1423	10.4	6.8	561,000	8,248,000
North Carolina	62.6	1.2	1921	48.2	2.8	330	50.3	2.6	358	51.1	2.3	479	63.9	1.3	1442	10.0	8.1	663,000	8,156,000
North Dakota	2.6	0.4	1484	15.0	3.6	100	13.0	3.4	100	13.0	3.4	100	2.5	0.4	1384	0.9	4.4	21,000	476,000
Ohio	39.9	1.2	1553	29.0	2.4	365	31.0	2.5	352	31.5	2.1	470	41.1	1.4	1083	12.4	9.8	419,000	4,274,000
Oklahoma	25.9	1.2	1555	18.9	3.5	127	31.5	2.2	447	31.2	2.2	455	25.5	1.3	1100	6.7	8.1	378,000	4,681,000
Oregon	40.8	0.9	2715	40.0	4.9	100	36.7	4.6	109	36.6	4.2	134	40.8	0.9	2581	1.5	1.4	141,000	10,235,000
Pennsylvania	65.8	1.2	1580	34.0	2.4	382	45.0	2.9	291	41.0	2.2	502	69.3	1.4	1078	12.2	7.6	590,000	7,727,000
Rhode Island	70.3	3.0	200	54.0	5.0	100	40.0	4.9	100	51.0	5.0	100	82.0	3.8	100	37.6	27.3	54,000	199,000
South Carolina	64.6	1.6	1130	47.1	3.8	170	46.7	3.6	195	48.9	3.0	270	66.2	1.7	860	8.9	6.8	352,000	5,215,000
South Dakota	5.7	0.6	1371	21.0	4.1	100	13.0	3.4	100	14.0	3.5	100	5.7	0.6	1271	0.8	2.1	24,000	1,143,000
Tennessee	57.1	1.4	1511	39.2	3.4	212	45.2	2.7	330	43.8	2.5	388	58.6	1.6	1123	10.4	8.0	497,000	6,232,000
Texas	23.4	0.6	5314	32.0	1.8	666	31.3	1.4	1,086	31.4	1.3	1212	23.0	0.6	4102	4.9	6.6	1,058,000	16,052,000
Utah	17.8	0.8	2441	15.0	3.6	100	16.2	2.6	204	16.4	2.6	207	17.8	0.8	2234	2.7	2.5	98,000	3,909,000
Vermont	81.5	2.2	412	53.0	5.0	100	51.0	5.0	100	53.0	5.0	100	82.3	2.2	312	2.8	1.8	36,000	2,015,000
Virginia	66.7	1.3	1540	34.8	3.2	224	38.6	2.8	306	39.8	2.5	372	69.6	1.4	1168	9.6	5.7	401,000	7,012,000
Washington	47.2	0.9	2198	32.8	3.3	198	34.1	3.0	255	34.6	2.7	321	47.8	0.9	1877	5.1	3.7	310,000	8,308,000
West Virginia	81.4	1.4	832	47.0	5.0	100	62.0	4.9	100	61.0	4.9	100	82.3	1.5	732	4.1	3.1	156,000	5,110,000
Wisconsin	47.7	1.4	1403	29.2	3.8	144	30.9	2.9	262	31.8	2.7	305	48.7	1.5	1098	5.4	3.6	250,000	6,927,000
Wyoming	14.5	0.7	2322	9.0	2.9	100	20.5	3.0	176	19.9	3.0	181	14.4	0.7	2141	1.9	2.6	96,000	3,670,000

US48[b]	34.2	0.2	78,102	35.0	0.5	9443	33.8	0.4	12,811	35.1	0.4	15,299	34.1	0.2	62,803	5.3	5.5	14,643,000	266,656,000
Alaska	na	na	na	38.2	1.6	970	39.8	2.1	1403	39.8	2.1	1497	na	na	na	4.8	na	2,936,000	na
Hawaii	34.9	1.2	2939	30.4	1.3	1278	40.5	1.4	1765	39.9	1.4	1952	33.8	1.5	987	17.6	20.1	117,000	583,000
US50[c]	na	na	na	35.0	0.5	11,400	34.9	0.5	14,303	35.8	0.4	18,748	na	na	na	5.3	na	17,696,000	na

SE, standard error; n, number of sampled photo-interpreted points.
[a] Percent of state classified as urban/community land.
[b] Lower 48 states, including the District of Columbia.
[c] All 50 states, including the District of Columbia.

Hawaii, national tree cover in urban/community areas is estimated at 35.8% (SE = 0.4) or 17.7 million hectares of tree cover (43.7 million acres). Statewide, percent tree cover is highest in New Hampshire (88.9%, SE = 1.8) and lowest in North Dakota (2.6%, SE = 0.4). In urban/community areas, percent tree cover is highest in Connecticut (67.4%, SE = 3.4) and lowest in Nevada (9.6%, SE = 1.8) (Table 1).

Impervious cover in the conterminous United States is estimated at 2.4% (SE = 0.1) or 18.4 million hectares of impervious cover (45.5 million acres). In contrast, urban/community areas have higher percent impervious cover at 17.5% (SE = 0.3) or 7.3 million hectares of impervious cover (18.0 million acres) (Table 2). Including Alaska and Hawaii, national impervious cover in urban/community areas is estimated at 14.9% (SE = 0.3) or 7.4 million hectares of impervious cover (18.2 million acres). State wide, percent impervious cover is highest in New Jersey (12.1%, SE = 1.6) and lowest in Wyoming (0.5%, SE = 0.1). In urban/community areas, percent impervious cover is highest in Nebraska (32.0%, SE = 4.7) and lowest in Wyoming (2.2%, SE = 1.1) (Table 2).

Overall, there was no statistical difference between urban/community percent tree cover and rural percent tree cover, but urban/community areas did have significantly higher percent impervious cover (+16.0%) (Table 3). However, differences in percent tree cover did vary by state, with nine states having significantly higher percent tree cover in urban/community areas than rural areas, and 26 states having significantly lower percent tree cover. In terms of impervious surfaces, all states showed an increase in percent impervious cover in urban/community land versus rural land in the state, with 46 having a statistically significant increase (Table 3).

Tree cover per capita in urban areas averaged 377 m^2 and was greatest in New Hampshire (1266) and lowest in Nevada (92). Impervious cover per capita averaged 274 m^2 and was greatest in Idaho (444) and lowest in New York (167) (Table 4). For the conterminous United States, tree cover per capita was 9512 m^2 and impervious cover per capita was 657 m^2.

Percent tree cover within urban areas and urban/community areas was correlated with overall state percent tree cover (Spearman correlation; $r = 0.87$ and $r = 0.89$, respectively). Percent tree cover in urban areas was negatively correlated with urban population density (Spearman correlation: $r = -0.43$), while percent impervious cover was positively correlated with urban population density (Spearman correlation: $r = 0.67$). Urban tree and urban impervious cover were negatively correlated (Spearman correlation: $r = -0.72$).

4. Discussion

4.1. Tree cover

Tree cover in the conterminous United States is an important landscape element, covering over 1/3 of the nation and occupying 266.7 million hectares. Even within urban lands where people and impervious surfaces are concentrated, tree cover is still a dominant element, covering approximately the same percent of land cover (35.0%). A previous urban tree cover study for the conterminous United States, based on advanced very high resolution radiometer (AVHRR) data and Landsat thematic mapper data (Zhu, 1994), estimated percent urban tree cover at 27%, with urban tree cover highest in forested regions (34.4%), followed by grassland areas (17.8%) and deserts (9.3%) (Nowak, Noble, Sisinni, & Dwyer, 2001). However this estimate was likely conservative based on the limitations of the AVHRR data (Dwyer et al., 2000).

Statewide tree cover varies, as expected, based on the local environment (e.g., precipitation, temperature, natural vegetation types). Tree cover within urban areas was correlated with overall

Table 2
Summary of percent impervious cover statewide, and within urban, community, and urban/community (UC) land.

	Percent impervious cover																		
State	Statewide	SE	*n*	Urban	SE	*n*	Comm.	SE	*n*	UC	SE	*n*	Rural	SE	*n*	%UC[a]	% of state imp. cover in UC	UC imp. cover (ha)	State imp. cover (ha)
Alabama	2.7	0.5	1366	15.2	2.8	164	8.2	1.4	413	8.3	1.3	446	2.1	0.5	920	9.5	28.8	105,000	366,000
Arizona	1.3	0.2	3105	37.9	4.1	140	13.3	1.5	487	13.8	1.5	500	0.6	0.2	2605	5.3	57.1	217,000	380,000
Arkansas	2.5	0.5	1146	25.0	4.3	100	15.5	2.5	213	14.9	2.4	222	1.9	0.5	924	4.4	26.8	91,000	340,000
California	2.9	0.2	5835	39.8	1.8	728	28.5	1.4	1083	26.9	1.3	1237	0.7	0.1	4598	8.4	77.1	931,000	1,207,000
Colorado	1.4	0.2	2205	28.4	4.3	109	17.4	2.6	207	17.2	2.5	233	1.0	0.2	1972	2.6	31.1	121,000	390,000
Connecticut	7.7	1.6	298	11.6	2.4	173	12.0	3.2	100	11.1	2.3	190	5.6	2.2	108	38.8	55.8	55,000	99,000
Delaware	6.2	1.7	200	19.0	3.9	100	21.0	4.1	100	17.0	3.8	100	4.0	2.0	100	17.2	46.9	15,000	33,000
Florida	6.9	0.6	1991	27.5	1.9	553	22.2	1.6	654	21.5	1.4	829	4.3	0.7	1162	15.3	47.3	492,000	1,041,000
Georgia	3.1	0.4	1801	17.7	2.0	367	13.6	1.8	352	13.5	1.5	542	2.0	0.4	1259	9.5	40.8	194,000	476,000
Idaho	1.1	0.2	2127	37.0	4.8	100	22.0	4.1	100	23.0	4.2	100	0.9	0.2	2027	0.8	17.3	41,000	238,000
Illinois	4.8	0.5	1374	30.7	2.5	329	30.8	2.4	380	26.1	2.0	468	2.8	0.6	906	8.6	46.2	325,000	702,000
Indiana	3.7	0.5	1081	25.5	3.2	188	25.6	3.0	207	22.6	2.6	266	2.0	0.5	815	8.0	49.5	170,000	343,000
Iowa	3.0	0.5	1265	27.0	4.4	100	20.4	2.9	191	19.5	2.8	200	2.4	0.5	1065	3.6	23.6	103,000	434,000
Kansas	2.2	0.4	1483	23.0	4.2	100	22.5	4.1	102	19.8	3.7	116	1.8	0.4	1367	1.8	16.4	76,000	461,000
Kentucky	2.3	0.5	1081	16.3	3.6	104	12.4	2.7	153	12.2	2.4	181	1.8	0.5	900	5.1	26.9	64,000	239,000
Louisiana	2.9	0.6	906	19.1	3.2	152	13.1	2.2	236	12.2	2.0	278	2.3	0.6	628	6.2	26.1	93,000	356,000
Maine	3.2	0.6	834	19.0	3.9	100	13.1	3.1	122	12.5	2.9	128	2.8	0.6	706	4.0	15.5	42,000	272,000
Maryland	6.1	1.0	451	21.6	3.2	167	21.6	3.2	167	19.0	2.7	210	2.4	1.0	241	21.9	68.6	113,000	164,000
Massachusetts	7.4	1.1	472	16.7	2.4	251	16.1	2.9	161	14.5	2.0	304	3.0	1.3	168	38.6	75.3	119,000	158,000
Michigan	4.1	0.5	1492	31.5	2.7	289	29.0	2.8	262	26.8	2.3	377	2.3	0.5	1115	7.1	47.0	288,000	612,000
Minnesota	2.2	0.3	1788	24.1	3.4	158	13.2	1.7	379	13.3	1.7	400	1.7	0.3	1388	4.9	29.1	141,000	483,000
Mississippi	3.6	0.7	902	17.0	3.8	100	12.7	2.4	189	11.9	2.3	201	3.2	0.7	701	4.6	15.0	68,000	450,000
Missouri	2.4	0.4	1399	22.0	3.2	164	18.3	2.4	257	18.0	2.3	289	1.6	0.4	1110	4.6	34.8	150,000	431,000
Montana	0.7	0.1	3239	28.0	4.5	100	8.3	1.8	240	8.4	1.7	251	0.6	0.1	2988	2.0	22.7	64,000	284,000
Nebraska	1.6	0.3	1365	28.0	4.5	100	33.0	4.7	100	32.0	4.7	100	1.3	0.3	1265	1.0	19.7	62,000	316,000
Nevada	0.6	0.1	2177	49.0	5.0	100	8.8	1.7	262	9.2	1.8	271	0.4	0.1	1906	2.7	41.2	72,000	176,000
New Hampshire	5.0	1.3	325	18.0	3.8	100	9.0	3.5	67	12.0	3.2	100	4.2	1.4	225	10.0	23.9	29,000	120,000
New Jersey	12.1	1.6	409	22.5	2.7	240	21.9	3.1	183	19.9	2.4	287	6.5	2.1	122	42.1	69.0	169,000	244,000
New Mexico	1.0	0.2	2576	24.0	4.3	100	14.7	2.8	163	15.4	2.7	175	0.7	0.2	2401	1.7	26.1	81,000	312,000
New York	4.5	0.4	1923	27.4	2.4	347	24.3	2.2	375	22.4	1.9	500	2.4	0.4	1423	10.4	51.5	295,000	573,000
North Carolina	4.9	0.5	1921	18.5	2.1	330	17.3	2.0	358	15.7	1.7	479	3.7	0.5	1442	10.0	32.1	203,000	633,000
North Dakota	1.1	0.3	1484	26.0	4.4	100	10.0	3.0	100	10.0	3.0	100	1.0	0.3	1384	0.9	7.9	16,000	204,000
Ohio	5.5	0.5	1553	27.1	2.3	365	28.1	2.4	352	24.5	2.0	470	2.8	0.5	1083	12.4	55.2	326,000	590,000
Oklahoma	2.7	0.4	1555	30.7	4.1	127	13.0	1.6	447	12.7	1.6	455	2.0	0.5	1100	6.7	31.2	155,000	496,000
Oregon	0.8	0.1	2715	26.0	4.4	100	22.0	4.0	109	19.4	3.4	134	0.5	0.1	2581	1.5	36.8	75,000	203,000
Pennsylvania	4.6	0.5	1580	24.6	2.2	382	18.6	2.3	291	19.1	1.8	502	2.5	0.5	1078	12.2	51.3	275,000	536,000
Rhode Island	10.9	2.0	200	26.0	4.4	100	36.0	4.8	100	24.0	4.3	100	3.0	1.9	100	37.6	82.8	26,000	31,000
South Carolina	4.4	0.6	1130	17.1	2.9	170	15.4	2.6	195	14.1	2.1	270	3.5	0.7	860	8.9	28.3	101,000	359,000
South Dakota	1.7	0.4	1371	33.0	4.7	100	18.0	3.8	100	18.0	3.8	100	1.6	0.4	1271	0.8	9.0	30,000	338,000
Tennessee	3.4	0.4	1511	19.3	2.7	212	15.8	2.0	330	14.7	1.8	388	2.0	0.4	1123	10.4	45.4	167,000	367,000
Texas	2.0	0.2	5314	25.1	1.7	666	16.4	1.1	1086	16.5	1.1	1212	1.2	0.2	4102	4.9	41.5	556,000	1,340,000
Utah	0.9	0.2	2441	36.0	4.8	100	11.3	2.2	204	11.6	2.2	207	0.6	0.2	2234	2.7	34.2	69,000	201,000
Vermont	1.9	0.6	412	22.0	4.1	100	20.0	4.0	100	17.0	3.8	100	1.4	0.7	312	2.8	25.4	12,000	46,000
Virginia	4.3	0.5	1540	21.9	2.8	224	17.3	2.2	306	16.1	1.9	372	3.0	0.5	1168	9.6	36.3	163,000	448,000
Washington	1.6	0.2	2198	26.3	3.1	198	19.2	2.5	255	18.1	2.1	321	0.7	0.2	1877	5.1	56.5	162,000	287,000
West Virginia	2.0	0.5	832	20.0	4.0	100	14.0	3.5	100	12.0	3.2	100	1.6	0.5	732	4.1	24.6	31,000	128,000
Wisconsin	2.8	0.4	1403	22.2	3.5	144	15.6	2.2	262	14.8	2.0	305	2.1	0.4	1098	5.4	28.5	116,000	406,000

Wyoming	0.5	0.1	2322	30.0	4.6	100	2.3	1.1	176	2.2	1.1	181	0.4	0.1	2141	1.9	9.3	11,000	115,000
US48[b]	2.4	0.1	78,102	25.5	0.5	9443	18.2	0.3	12,811	17.5	0.3	15,299	1.5	0.1	62,803	5.3	39.5	7,287,000	18,426,000
Alaska	na	na	na	20.7	1.3	970	0.9	0.4	1403	0.9	0.4	1497	na	na	na	4.8	na	70,000	na
Hawaii	2.1	0.3	2939	21.5	1.1	1278	7.5	0.5	1765	8.0	0.5	1952	0.8	0.3	987	17.6	67.2	24,000	35,000
US50[c]	na	na	na	25.5	0.5	11,400	15.1	0.3	14,303	14.9	0.3	18,748	na	na	na	5.3	na	7,380,000	na

SE, standard error; *n*, number of sampled photo-interpreted points.

[a] Percent of state classified as urban/community land.

[b] Lower 48 states, including the District of Columbia.

[c] All 50 states, including the District of Columbia.

Table 3

Difference in percent tree and impervious cover between urban/community areas and rural areas by state (urban/community cover minus rural cover – positive values indicate greater cover in urban/community areas).

State	Tree cover[a]	State	Impervious cover[b]
Kansas	17.3*	Nebraska	30.7*
Nebraska	11.5*	California	26.2*
Illinois	10.7*	Michigan	24.5*
North Dakota	10.5*	Illinois	23.2*
Iowa	8.9*	Idaho	22.1*
Montana	8.9*	Ohio	21.6*
Texas	8.5*	Rhode Island	21.0*
South Dakota	8.3*	Indiana	20.5*
Oklahoma	5.7	New York	20.0*
Wyoming	5.5	Oregon	18.9*
Delaware	2.0	Kansas	18.0*
Minnesota	−0.9	Washington	17.3*
Utah	−1.4	Florida	17.2*
Arizona	−1.7	Iowa	17.1*
Nevada	−2.0	Maryland	16.6*
Indiana	−2.2	Pennsylvania	16.6*
Oregon	−4.3	South Dakota	16.4*
Colorado	−5.3	Missouri	16.4*
New Jersey	−6.5	Colorado	16.1*
New Mexico	−7.2*	Vermont	15.6*
Connecticut	−8.6	Texas	15.3*
Missouri	−9.2*	New Mexico	14.7*
Massachusetts	−9.3	New Jersey	13.4*
Ohio	−9.6*	Arizona	13.2*
Maryland	−10.9	Virginia	13.1*
California	−12.0*	Delaware	13.0*
North Carolina	−12.7*	Arkansas	13.0*
Washington	−13.2*	Tennessee	12.6*
Georgia	−13.6*	Wisconsin	12.6*
Tennessee	−14.8*	North Carolina	12.0*
Arkansas	−15.5*	Minnesota	11.6*
Alabama	−16.4*	Massachusetts	11.5*
Wisconsin	−16.9*	Georgia	11.4*
South Carolina	−17.3*	Utah	11.0*
Mississippi	−17.6*	Oklahoma	10.7*
Louisiana	−17.7*	South Carolina	10.6*
West Virginia	−21.3*	Kentucky	10.4*
Florida	−23.0*	West Virginia	10.4*
New York	−25.0*	Louisiana	9.9*
New Hampshire	−25.5*	Maine	9.7*
Michigan	−26.3*	North Dakota	9.0*
Idaho	−28.2*	Nevada	8.9*
Pennsylvania	−28.3*	Mississippi	8.7*
Vermont	−29.3*	Montana	7.8*
Virginia	−29.8*	New Hampshire	7.8
Rhode Island	−31.0*	Alabama	6.1*
Maine	−32.1*	Connecticut	5.5
Kentucky	−37.9*	Wyoming	1.8
US48[c]	1.0	US48[c]	16.0*
Alaska	na	Alaska	na
Hawaii	6.1*	Hawaii	7.2*

[a] Difference in tree cover (urban/community cover – rural cover).

[b] Difference in impervious cover (urban/community cover – rural cover).

[c] Lower 48 states, including the District of Columbia.

* Significant difference among 95% confidence intervals.

state tree cover and negatively correlated with urban population density. Connecticut, Massachusetts and New Hampshire have greater than 60% tree cover in both their urban and community lands. These states have high percent tree cover naturally and have below average urban population densities (U.S. urban population density = 931 people/km^2; CT = 655; MA = 802; NH = 506). Thus the naturally forested environment in conjunction lower urban population densities can help enhance percent tree canopy cover. Other factors, such as management programs to enhance tree cover in urban areas also likely play a role in sustaining urban tree cover in these states. The lower population densities may also lead to lower

Table 4
Tree and impervious cover (m^2) per capita in urban areas by state.

Tree cover		Impervious cover	
State	m^2/capita	State	m^2/capita
New Hampshire	1266	Idaho	444
Connecticut	1015	Arkansas	415
Alabama	988	Wyoming	408
Maine	959	Oklahoma	406
South Carolina	928	Montana	386
North Carolina	912	Nevada	377
Georgia	854	Michigan	365
Vermont	852	South Dakota	365
Massachusetts	804	Arizona	363
West Virginia	804	Vermont	360
Arkansas	714	New Hampshire	356
Mississippi	698	North Carolina	350
Tennessee	678	West Virginia	349
Rhode Island	565	New Mexico	346
Delaware	472	Maine	337
New Jersey	459	South Carolina	336
Louisiana	423	Indiana	336
Michigan	401	Tennessee	335
Pennsylvania	395	Utah	326
Virginia	395	Iowa	321
Oregon	391	Ohio	317
Florida	391	Florida	306
Missouri	376	Washington	297
Kentucky	374	Mississippi	297
Washington	371	Georgia	291
Minnesota	345	Pennsylvania	285
Texas	342	Alabama	284
Ohio	340	Nebraska	278
Maryland	338	Rhode Island	272
Wisconsin	334	North Dakota	270
Kansas	323	Texas	268
Indiana	294	Minnesota	267
Iowa	273	Kansas	266
New York	252	Missouri	265
Oklahoma	250	Illinois	259
South Dakota	232	California	255
Illinois	223	Wisconsin	255
Nebraska	179	Oregon	254
New Mexico	173	Colorado	254
Idaho	160	Louisiana	250
Arizona	158	Virginia	248
Colorado	156	Delaware	236
North Dakota	156	Kentucky	227
Utah	136	Maryland	221
California	128	Massachusetts	209
Montana	124	New Jersey	205
Wyoming	122	Connecticut	176
Nevada	92	New York	167
US48[a]	377	US48[a]	274
Alaska	642	Alaska	348
Hawaii	260	Hawaii	189
US50[b]	377	US50[b]	274

[a] Lower 48 states, including the District of Columbia.
[b] All 50 states, including the District of Columbia.

percent impervious cover (Table 2) and allow more space available for natural regeneration in these areas.

Dominant factors that affect urban tree cover are surrounding natural environment and land-use distribution (Nowak et al., 1996). The surrounding natural environment has a substantial influence as it can provide seed sources for new trees and an environment that may or may not be conducive to tree establishment and growth. The land use patterns determine the amount of potential available space for trees (non-impervious cover) and the type of management, planting or natural regeneration that may occur. Thus the mix of tree and impervious surfaces in urban areas is influenced by the social environment in the context of the natural environment.

Natural regeneration can play an important role in urban tree cover. In forested regions where natural regeneration readily occurs, human actions tend to prohibit tree cover through such actions as constructing impervious surfaces, soil compaction, and mowing of lawns. The reduction of these actions could increase tree cover in urban areas within naturally forested regions. Managers often supplement natural regeneration with tree planting and maintenance to sustain urban tree canopy in the United States.

However, in areas where natural regeneration is not common (i.e., grassland and desert areas), much of the urban tree cover comes through human actions of planting and maintenance. The percentage of the urban tree population that is 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). Enhancing tree cover in environments that tend to be precipitation limited involves various costs, both economic and environmental. Planting trees in these environments can produce substantial benefits for the urban population, but often require water or economic resources that may be scarce.

4.2. Urban vs. rural tree cover

Urban/community areas showed various differences in tree cover relative to the rural land in the states. In predominantly grassland states, urban/community development tends to increase tree cover, while in forested states it tends to decrease tree cover. In more desert states, tree cover did not change much or only declined slightly. Thus urban development has the potential to increase tree cover as population densities increase in some areas.

Some of the differences in tree cover between rural and urban/community lands may be associated with differences in natural vegetation types across a state (e.g., most states are not entirely forested) and locations of cities within a state. As cities are often located near water sources (e.g., rivers), cities in predominantly grassland states may be developed in areas with naturally higher tree cover (e.g., riparian zones) than more rural areas. Thus some of the differences associated with relatively higher tree cover in urban/community vs. rural lands in grassland states may be due to location, rather than human-influenced tree cover processes (e.g., tree planting) associated with urbanization. Also, agriculture is a dominant land use in rural lands in grassland states, and agricultural processes tend to limit tree cover in rural areas of these states.

4.3. Impervious cover

Impervious cover, as expected, is a less dominant cover type nationally (2.4% or 18.4 million hectares), but increases in dominance in urban areas (25.5%). The ratio of tree to impervious cover is about 14:1 nationally, but only about 1.4:1 within urban areas, a 10 fold difference. There were no substantial differences in impervious cover by natural vegetation types, but differences were exhibited based on population density. States with more densely populated areas, typically in the Northeast, tended to have higher percent impervious surfaces. States with greater than 6% impervious surfaces were New Jersey (12.1), Rhode Island (10.9), Connecticut (7.7), Massachusetts (7.4), Florida (6.9), Delaware (6.2) and Maryland (6.1).

Percent urban impervious cover averaged 25%, but can be higher at the city level in densely populated areas. Impervious cover in 20 U.S. cities averaged 43% and was as high as 61.1% in New York City (Nowak & Greenfield, 2012). Within urban areas, impervious cover was over 30% in 10 states and was a low as 11.6% in Connecticut. One reason for the relatively low estimate of impervious cover in Connecticut could be the high percent tree cover within urban Connecticut (66.5%). Interpreters conducted dual classifications at each point (tree and impervious), but in heavily tree covered areas, the interpreter may not be able to see what is under the tree canopy. Percent impervious cover in urban areas was negatively correlated with percent urban tree cover. Thus, impervious cover estimates are likely conservative, particularly in more heavily tree covered areas.

One potential approach to improve estimation of impervious surface cover is to use leaf-off imagery. Various satellite-based approaches have estimated impervious surface for the United States, but likely underestimate impervious cover. NLCD estimates impervious cover in the conterminous United States at about 1.3%, while another satellite-based study estimated it at 1.1% (Elvidge et al., 2007). Both of these satellite-based estimates have lower estimates than found in this photo-interpretation-based study (2.4% impervious cover). Part of the reason for this difference may be due to the time period between estimates. Both satellite-based studies were based on data circa 2000, while this study's imagery was circa 2005. Thus new impervious surfaces constructed between 2000 and 2005 could cause part of the difference in estimation, but likely not all. It is possible that satellite-derived estimates have limitations in the estimation of impervious cover that may also be related to tree cover (leaves, branches, shadows) obscuring impervious cover or the relatively coarse resolution of the imagery (30 m to 1 km pixel resolution). As photo-interpreters were asked to record impervious cover beneath tree canopies by looking for clues of impervious cover (e.g., obvious extensions of roads, buildings, parking lots beneath tree cover), there is a chance that interpreters overestimated impervious cover in these cases as they could not directly see beneath the tree canopies. However, it is more likely that interpreters underestimated impervious cover.

Though a relatively small element of cover nationwide, impervious cover can be a significant element in urban areas and significantly affect air temperatures, energy use, water quality and stream flow, and consequently human health and well-being in cities. Percent impervious cover is related to local population density, but various designs can help minimize the environmental impacts of impervious surfaces while still providing the necessary transportation and building needs of an urban population (e.g., pervious paving, green roofs). One of the keys in developing the urban landscape is to understand the social and natural environments and then design and manage with and within nature to sustain optimal benefits for the urban residents, while minimizing costs (e.g., McHarg, 1992).

Urban land, where relatively high densities of people reside, and community land, which is defined by political boundaries, had similar results in relation to tree cover. However, community areas had significantly lower percent impervious cover (25.5 vs. 18.2%). This lower percent impervious cover is likely due to lower population densities in the community areas (urban population density = 931 people/km^2; community population density = 594 people/km^2), and therefore less associated development. Impervious cover per capita tended to be highest in states with lowest population densities, indicating that percent impervious cover in urban areas likely increases at slower rates than population density increases. That is, though population density is correlated with impervious surfaces, there is likely some threshold of impervious cover where this cover does not need to increase much to sustain increasingly higher population densities.

4.4. *Optimal tree cover*

One of the key questions in urban landscape design is what is the optimal mix of tree and impervious cover? The answer to this question depends upon a number of factors, including natural vegetation cover, the costs and benefits associated with tree cover in the region, population density, and the interests/needs of local community members. Optimal tree cover in forested regions will likely be higher than in grasslands or deserts. Determining the true optimal tree cover for an area would depend upon a more in-depth analysis of costs and benefits derived from tree cover and community interests in a region, and have not been quantified yet for any region. However, setting of minimal goals for tree canopy cover can facilitate standards and management plans to sustain tree cover and associated environmental services in urban and urbanizing areas.

The data illustrate that tree cover levels above 60% are possible and urban tree cover between 40 and 60% is common in forested states. Thus a minimum 40% urban tree cover goal is attainable in many forest regions. However, at the local scale, as population density and impervious cover increase, lower percent tree cover levels would be expected. Based on the state data, reasonable minimum urban tree cover goals for grassland areas would be 20% and for deserts, 15%. These goals are near the current average cover percentages and should be attainable by most cities as a minimum. More progressive goals to enhance ecosystem services by trees could be set at higher levels than the minimum and still should be attainable by most cities, but at increased environmental or economic costs depending upon location.

The minimum goals described here are based on the results of this national analysis. However, many local factors determine local tree cover, not least of which is human management desires or goals for an area. Thus local managers should set locally specific tree goals based on local conditions, desires and data sets. The national data sets here could help in providing general guidelines for determining local goals and for comparison of average cover among states. Local tree cover goals and associated management plans can help sustain desired tree cover levels and potentially reverse the recent decline in urban tree cover nationally (Nowak & Greenfield, 2012).

One way to attain an optimal structure of natural and artificial surfaces in an urban area is to quantify the current conditions and then develop a local management plan to attain the desired structure of trees and impervious surfaces. To help quantify the cover types within an area, a no-cost tool (i-Tree Canopy) is available (www.itreetools.org) that allows users to photo-interpret a city using Google Map® images. This program quantifies the percent cover and associated standard error for each cover class based on interpreter's classification of random points. Photo-interpretation is relatively quick, easy and accurate (depending upon the skills of the interpreter), but does not produce a map of the locations of the cover classes, rather just an estimate of the percent or total area occupied by a cover class within a specific geography.

4.5. *Limitations*

Though photo-interpretation provides a relatively simple and inexpensive means to assess tree and impervious cover, there are various limitations to the cover estimates. These limitations generally relate to the ability of the interpreter to accurately distinguish the various cover classes. Differing spatial resolutions and image acquisition dates can potentially affect interpretation, but interpreters could choose to not classify points and 99% of the points were classified as interpretable. Different interpreters can also potentially classify points differently, but quality control checks were in close agreement. Regardless of whether humans classify images or computers are used to derive cover classes, both methods have limitations. Though photo-interpretation is often more tedious and does not produce a detailed cover map, the human ability to distinguish objects can be used to produce accurate cover estimates in a timely fashion through random sampling.

5. Conclusion

Percent tree and impervious cover differ significantly among states. Urban development increases the amount of impervious cover, but can increase or decrease tree cover depending upon the local environment and human interactions. Urban development in predominantly grassland states tends to increase percent tree cover in contrast to rural lands. Urban development in forested regions tends to decrease percent tree cover relative to rural lands, but the reduction varies among states. These patterns indicate the important role of urban development patterns and social management/planning roles on enhancing or sustaining (reducing the loss of) tree cover in urban areas in the context of the natural environment. Cover data of a city or region can provide a baseline for developing management plans, setting tree cover goals, and for monitoring change through time. As human management is an important factor along with nature in determining the extent of tree cover in urban areas, management plans can be developed to enhance tree cover (and/or reduce impervious cover) and consequently enhance numerous ecosystem services related to human health and well-being. Photo-interpreted data on cover in urban areas and elsewhere can provide an accurate means of assessing cover types and changes in cover through time to help managers and planners make informed decisions on how to better improve local landscapes and the environment.

Acknowledgments

Funding for this project was provided, in part, by the U.S. Forest Service's RPA Assessment Staff and State & Private Forestry's Urban and Community Forestry Program. The use of trade, firm, or corporation names in this article is for the information and convenience of the reader. Such use does not constitute an official endorsement or approval by the U.S. Department of Agriculture Forest Service of any product or service to the exclusion of others that may be suitable. We thank Mike Boarman, Chris Sorrentino, Maude Morse, Sebastian Varela, Allison Bodine and Tian Zhou for photo-interpretation. We also thank John Stanovick for his statistical assistance and review, and Anne Cumming and Susan Stein for their review of an early draft of the manuscript.

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