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Regional Differences in Upland Forest to Developed (Urban) Land Cover Conversions in the Conterminous U.S., 1973–2011

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Abstract: In this U.S. Geological Survey study of forest land cover across the conterminous U.S. (CONUS), specific proportions and rates of forest conversion to developed (urban) land were assessed on an ecoregional basis. The study period was divided into six time intervals between 1973 and 2011. Forest land cover was the source of 40% or more of the new urban land in 35 of the 84 ecoregions located within the CONUS. In 11 of these ecoregions this threshold exceeded in every time interval. When the percent of change, forest to urban, was compared to the percent of forest in each ecoregion, 58 ecoregions had a greater percent of change and, in six of those, change occurred in every time interval. Annual rates of forest to urban land cover change of 0.2% or higher occurred in 12 ecoregions at least once and in one ecoregion in all intervals. There were three ecoregions where the above conditions were met for nearly every time interval. Even though only a small number of the ecoregions were heavily impacted by forest loss to urban development within the CONUS, the ecosystem services provided by undeveloped forest land cover need to be quantified more completely to better inform future regional land management.

Keywords: Forest to urban developed land cover change; urbanization; conterminous U.S.; ecoregions; remote sensing

1. Introduction

Forests are substantial land cover sources for new urbanization both in the U.S. and globally [1–3]. Cumulatively, the increase in urban land and related types of development, such as roads and other exurban infrastructure, can cause a reduction of forest extent, fragmentation of wildlife habitat, and changes to hydrology and other regulating ecosystem services, such as carbon storage [4]. Due to geographic differences in human population and demographics, biophysical settings, and other factors, the impact of forest land cover conversion to new developed built-up land can be highly variable. Replacement of forest by urban development is also one of the most permanent changes to the environment [5] and may become even more important in regards to climate change effects on a growing number of people [6–8].

The growth of urban areas has been inescapable for decades, has tended to be sprawling, and is expected to continue to have substantial impact on land cover in the future [5,9]. However, mitigation is increasingly recognized as important, and there are new approaches to planning and managing urban ecological systems that could impact future trends, including consideration of urban forests and the sustainability of surrounding landscapes [10–13]. The role of forested land cover within, and surrounding, urban areas, and how best to mitigate the ongoing negative externalities of forest to urban developed land cover change is just one of the management pieces needed in understanding changed forest conditions in the near future [14].

Urbanization is a major driver of forest land cover change that needs renewed focus to analyze its widespread implications and potential impacts to human well-being [15]. A number of studies have conducted assessments of forest to urban developed land cover conversion either as their main emphasis or as part of the overall aspect of increased urbanization but these works tend to be scale limited by metropolitan area [16–19] or by region [20–23] or by temporal interval if done at a near national scale [24]. This research is the first to access near-national scale (CONUS) forest land cover to urban land change across a much longer time span (1973–2011) using similar remote sensing-derived datasets for six time-step intervals. Although near-national in overall scale, results are presented using a meso-scale ecoregional geographic framework that links similar land forms, vegetation, soils, and land use [25,26]. Using several proportional and rate conversion metrics, this work shows what ecoregions have been heavily impacted by forest to urban developed land cover conversion during the study period and where this type of land-use change has been much less of an issue.

2. Materials and Methods

2.1. Definitions of "Forest" and "Developed Land" Land Covers

This investigation does not explore urban tree cover or urban forestry; rather, we focus attention on conversion of forest land cover, as defined by two U.S. Geological Survey (USGS) datasets, to a land cover that has more anthropogenic characteristics than other types of features. Both the USGS Land Cover Trends project (LC Trends) and the National Land Cover Database (NLCD) definitions of forests are fairly simple; LC Trends defines forest land cover as 10% or more tree density and NLCD defines it as 20% or more for tree density as well as adding a height greater than five meters [27,28]. Urban developed land cover definitions for each data set are more complex but include that the land is either dominated by built and impervious features or a matrix of structures and vegetation or highly managed vegetation such as NLCD's "developed, open space" which is mostly lawn grasses [27,28]. Although such land cover definitions leave the impression of great precision where the semantics of what is "forest" and what is "urban" can be debated, most of the land change described in this research is of non-human occupied tree-dominated land (undeveloped forest land cover) being converted to residential subdivisions, commercial and industrial centers, road networks and right-of-ways, and other built features that are different land uses than what was found previously in the same location.

2.2. Materials

The land cover change data used in this research come from two different published (see additional citations in the 2.4 Limitations sub-section) USGS datasets that span two different time periods which, together, provide a nearly 40-year study period of forest land cover conversion to developed (urban and built-up) land. The first dataset is the USGS LC Trends project [1,29,30] that is based on sampled areas of U.S. Environmental Protection Agency (EPA) Level III ecoregions [31]. Each of the more than 2700 sample "blocks" had dates (circa 1973, 1980, 1986, 1992, and 2000) of modified Anderson 1 [32] land cover (e.g., forest, developed and built-up, agriculture, wetlands, and others) manually interpreted from imagery of various Landsat (Multi-Spectral (MSS), Thematic Mapper (TM), and Enhanced Thematic Mapper+ (ETM+) satellite sensors. Individual sample block land cover maps when compared between dates provide the change data that have estimates of land cover change that are statistically based at the ecoregion scale. The second USGS land cover change dataset is the

NLCD [33], which is a wall-to-wall mapping effort also derived using the data from several Landsat sensors (TM, ETM+) in an automated fashion to produce the Anderson II land cover [32] for the entire nation. Although the first NLCD (1992 iteration- [34]) was created using Landsat imagery from the early 1990s, we are using the iterations from circa 2001, 2006, and 2011 to complement and extend the land cover change record of the LC Trends project. The NLCD land cover data are at a 30 × 30 meter resolution (the innate resolution of the TM and ETM+ sensors) whereas the LC Trends sampled data are at a 60 × 60 meter resolution to enable comparison with MSS (data from 1973, 1980, and sometimes 1986) to the TM and ETM+ eras. At first glance, this may seem to be an issue but because individual maps from each of the datasets are not being directly compared to each other, only area estimates and percentages of land cover composition, the two different resolution sizes can work together.

2.3. Methods

We examined four land-cover change metrics that were easy to obtain from the datasets. These metrics included a threshold amount (⩾40%) of how much new urban developed land cover came from forest, the proportion of forest to developed land cover change that exceeded the proportion of forest land cover in the ecoregion, and a threshold rate of annual forest to urban developed land cover change for each time interval. Each of these metrics were used for each time interval. A final combination metric summed where the other metrics were met in most time intervals. Each of these metrics provides additional information about forest to urban developed land cover change.

The LC Trends project data already existed for estimating area of forest to urban developed land cover change for each ecoregion (See "LC Trends and NLCD" Excel in the supplemental material) for the first four time intervals (1973 through 2000). We were interested in determining the percent of forest to urban developed area in relation to the overall gain in urban developed land cover between dates, and did so by using the area estimates of forest to developed land cover change and dividing by the overall change in developed land cover (Equation (1), also see Supplemental Material).

$$\%\ new\ urban\ from\ forest = \frac{amount\ \ (sq.km)\ \ of\ new\ urban\ from\ forest}{amount\ \ (sq.km)\ \ of\ new\ urban} \tag{1}$$

Equation (1) represents the percent of urban developed land cover from forest land cover.

A similar exercise was done with the NLCD land cover change data for the final two time intervals (2001 through 2011). However, because NLCD maps land cover at an Anderson Level II classification the changes from the three different types of forest (deciduous, evergreen, and mixed) to the four different types of urban developed land covers (developed-open space, developed-low intensity, developed-medium intensity, and developed-high intensity), had to be added up for each individual ecoregion (See "NLCD Classes to LC Trends Classes" in the supplemental material). The overall pixels of "forest to urban developed land cover change" (scaled up to Anderson I classifications here) were converted to square kilometers and then this area amount was divided by the area change in developed land between 2001 and 2006 and between 2006 and 2011 to derive the percentage of forest to urban developed land versus overall developed land cover change.

To determine the relationship between the percent of forest to urban development land cover change to the percent of forest land cover within the ecoregion a mean between each two dates of percent of forest land cover by ecoregion was calculated (Equation (2)). This allowed a single percentage for the land cover change data to be divided by a single percentage of forest land cover for each time interval (Equation (3)).The results of Equation (3) were then compared to the results from Equation (1).

$$average\ amount\ \ (sq.km)\ \ of\ \ forest = \frac{amount\ (sq.km) of\ \ forest\ on\ first\ date + amount\ (sq.km) of\ \ forest\ on\ second\ date}{2} \tag{2}$$

Equation (2) represents the average amount of forest land cover during a time interval.

$$\% \; of \; forest \; in \; ecoregion = \frac{average \; amount \; (sq.km) \; of \; forest}{area \; (sq.km) \; of \; ecoregion} \tag{3}$$

Equation (3) represents the percent of forest land cover in an ecoregion per time interval.

For the LC Trends data, the percentage of forest as a proportion of each ecoregion's land cover composition was already provided (See "LC Trends and NLCD" Excel in the supplemental material). For the NLCD data, the total number of pixels classified as any forest type were added up and converted to km^2 for each ecoregion and each date and then divided by the total area in each ecoregion to create the percentage of forest. Then the mean of forest percentages of two dates was calculated as was done with the LC Trends data.

The annual rate of forest to urban developed land cover change for each ecoregion was calculated by taking the area of forest to developed land cover change divided by the area of forest land cover found in the first date of each time interval. This quotient was then divided by the number of years in each time interval (Equation 4).

$$A = ((amount \; [sq.km] \; of \; new \; urban \; from \; forest) / (amount \; [sq.km] \; of \; forest \; in \; first \; date)) / (number \; of \; years \; in \; time \; interval) \tag{4}$$

A = Annual rate of forest to urban developed land cover change.

Equation (4) represents the annual rate of forest to urban developed land cover change per ecoregion per time interval.

The same procedure was done with both the LC Trends and the NLCD data. National CONUS results from the LC Trends project [1] found that 1% annual overall land cover change for an ecoregion was considered a high rate. The threshold of 0.2% annual, or one fifth of what would be considered high in overall change, would translate to a 1% loss in forest land cover to urbanization every five years given that no replacement "to forest" source occurred and the conversion rate was sustained. The conversion to urban developed land cover is considered a near-permanent type of change in contrast to cyclic natural resource-based changes such as forestry, and so we used the threshold of 0.2% annual forest to urban developed land change as "high" for this type of change.

2.4. Limitations

One of the limitations in our results relates to scale. The regional scale of the investigation may mask the forest to urban developed land cover change dynamics of individual metropolitan areas by dampening the local intensity of change across a more extensive geographic area. This may be more of a factor in an ecoregion dominated by one large metropolitan area versus multiple urban centers. Another aspect of this limitation is that metropolitan areas are commonly spread across several ecoregions such as the Houston urban area, which occupies area in both the Western Gulf Coastal Plains and the South Central Plains (ecoregions #34 and #35, respectively, in Figure 1) or the New York metropolitan area spread across the Atlantic Coastal Pine Barrens, the Northeastern Coastal Zone, and the Northern Piedmont (ecoregions #84, #59, and #64, respectively, in Figure 1). There may be other spatial frameworks that can overcome this scale obstacle with the more recent wall-to-wall NLCD land change data but to include the longer 27-year record of the LC Trends sampled data, the Level III ecoregions provide the most appropriate estimates of change.

Large-area remote-sensing land cover mapping efforts always have a certain degree of error. The USGS LC Trends project and the USGS-led NLCD are no exception. Typically, remote-sensing land cover mapping projects use accuracy assessments to measure the uncertainty in their results. The LC Trends sample-based results give the uncertainties of the estimates in confidence intervals of how well the sampling captured specific types of change. Showing the sampling uncertainties in Table 1 does not mean that the LC Trends results are specifically better than NLCD numbers. The NLCD team uses accuracy assessments for their specific land cover classes at the national and large-region scale, although these accuracy assessments tend not to be completed the same time the land cover datasets are released to the public. At the current time, only the 2001–2006 land cover change data set has an accuracy assessment completed, but forest to urban developed land cover change was not separately assessed in this analysis. Rather, it was "bundled" with other land cover change classes into a "to developed" category. The NLCD "to developed" change category had an accuracy of 72% nationally for user's accuracy and regionally (EPA regions that are different than ecoregions) ranging from 58% to 81% [35]. NLCD users often use pixel-count change results for their specific areas of study because national and large-region accuracy assessments tend not to be spatially relevant for smaller regions. The LC Trends land cover change data did not have a formal accuracy assessment, but because the LC Trends research team used higher-resolution aerial photography (typically what is used in accuracy assessments) for at least two different dates as a way to augment the manual interpretation of the Landsat imagery, as well as team "block reviews" for each ecoregion, LC Trends change statistics are considered highly accurate [1,30].

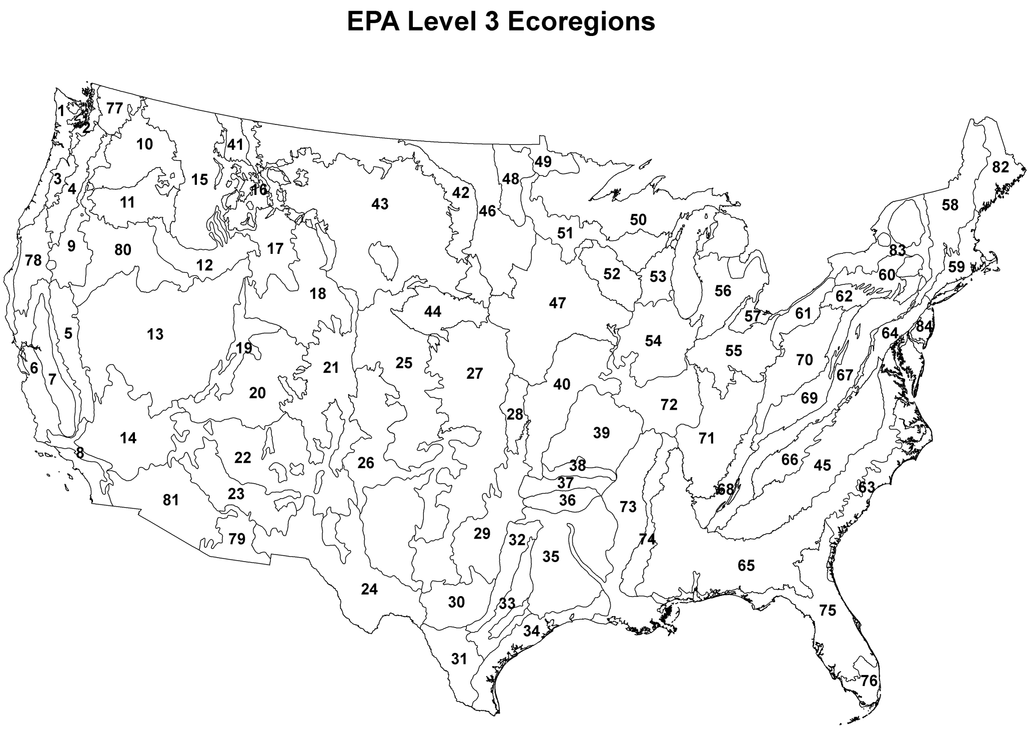

Figure 1. The numbers of the individual Level III EPA ecoregions (1999). Specific ecoregion numbers are called out in the text.

There is one time interval in which LC Trends and NLCD forest to urban developed land cover change overlap (1992 to 2000/01). Comparing these different datasets for the same time period is problematic, however, because NLCD 1992 [34] was created using methods different from those used for the subsequent NLCDs of 2001, 2006, and 2011 [33,36,37], and land cover change data found between the NLCD 1992 "Retrofit" [38] and NLCD 2001 [33] actually becomes a third dataset. Nonetheless, examining a map where this first NLCD change dataset compares area amounts for forest to urban developed land cover change and whether area amounts fall within LC Trends confidence intervals and where they do not is a worthwhile exercise. In a slight majority (46 out of 84) of the ecoregions, the NLCD 1992–2001 land cover change product did not have area amounts that were within LC Trends estimates confidence intervals (Figure 2). 39 LC Trends estimates were too low when compared to the NLCD change results and 7 LC Trends estimates were too high compared to NLCD (Figure 2). In some cases, the area difference between the two datasets was actually quite low. If a threshold of 10 km^2 or less was applied, 20 of the ecoregions where LC Trends were lower than NLCD would be eliminated and three ecoregions would be removed in cases where LC Trends estimates were higher than NLCD. Area amount discrepancies of over 100 km^2 between LC Trends and NLCD for the same time interval occurred in only two ecoregions, the Texas Blackland Prairies (ecoregion #32 in Figure 1) and the Western Allegheny Plateau (ecoregion #70 in Figure 1), 118 km^2 and 135 km^2, respectively.

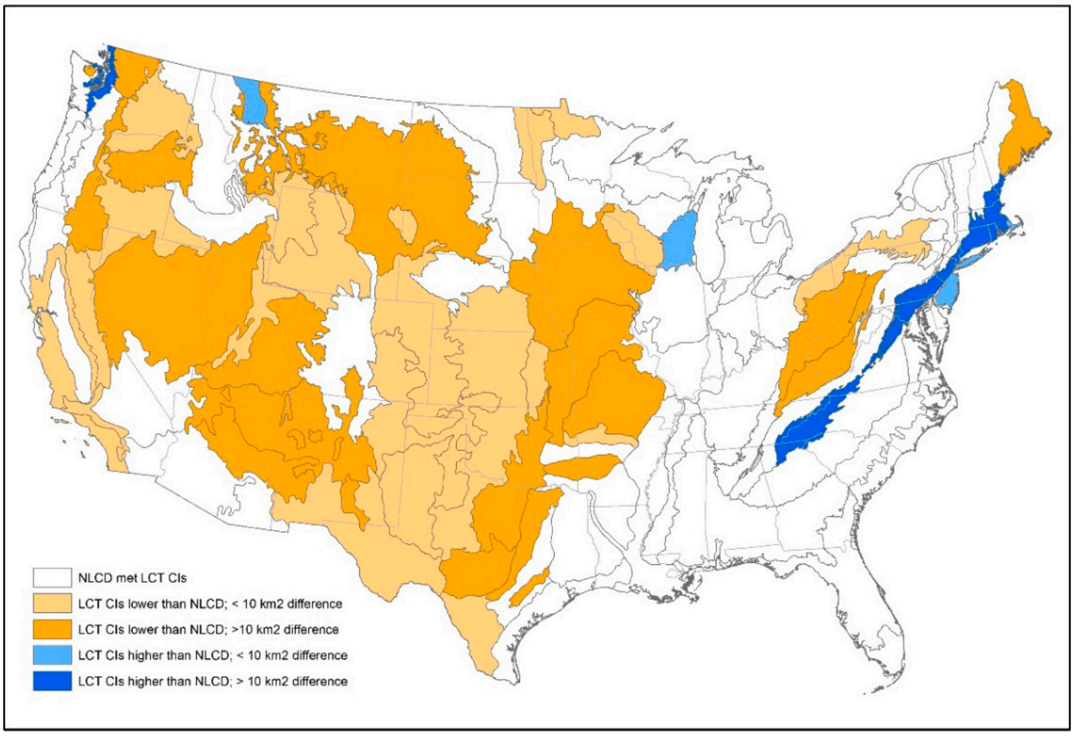

Figure 2. A comparison of forest to developed land cover area change between LC Trends (LCT) confidence intervals (CIs) estimates and the 1992 Retrofit NLCD- NLCD 2001 for the 1992–2000/2001 time interval.

Another potential limitation is the way in which the two different land cover change mapping efforts classified forested wetlands, especially in the Southeast and Gulf Coastal United States where these types of wetlands are prevalent. LC Trends placed forested wetlands into the broader "wetlands" land cover class, whereas NLCD mapped them as "woody wetlands" separate from emergent herbaceous wetlands. In neither case were these land cover classes included in our investigation. The issue here is not the difference between including forested wetlands within an Anderson I wetland classification or keeping them separate as an Anderson II class but that forested wetlands are notoriously hard to classify with high accuracy [39]. Some of the results from ecoregions from the above-listed larger regions may indicate classification confusion between what LC Trends called "upland" forest and what NLCD classified as "upland" forest compared to what was classified as "wetlands" and not included in the study. There may be other regional cases of differences between LC Trends and NLCD of how upland forest land cover is classified from other land covers.

Even though all of the above limitations may seem to call into question some of the results of this investigation, the combining of both the LC Trends and NLCD forest to urban developed land cover change provides the longest study period and the most geographically comprehensive inquiry into this type of land change within the United States. There are no other datasets comparable. The land cover change community has vetted numerous national- and regional-scale investigations using these two datasets [1,18,21,29,33–37,40–54] in spite of their imperfections. Instead of looking at the results of this investigation as precise measurements of change, they are better viewed as general observations of forest to urban developed land cover change at a CONUS regional scale.

Table 1. Ecoregions with forest as a substantial source of new development in any or all time intervals (all time intervals in bold). Ecoregions where at least 40% of new developed land cover came from forest.

Ecoregion	Forest to Urban, 1973–1980, km²	Forest to Urban as % of Total New Developed 1973–1980	Forest to Urban, 1980–1986, km²	Forest to Urban as % of Total New Developed 1980–1986	Forest to Urban, 1986–1992, km²	Forest to Urban as % of Total New Developed 1986–1992	Forest to Urban, 1992–2000, km²	Forest to Urban as % of Total New Developed 1992–2000	Forest to Urban, 2001–2006, km²	Forest to Urban as % of Total New Developed 2001–2006	Forest to Urban, 2006–2011, km²	Forest to Urban as % of Total New Developed 2006–2011
Coast Range	59 (±38)	75%	37 (±23)	58%	48 (±30)	72%	92 (±45)	72%			1	47%
Puget Lowland	**222 (±62)**	**85%**	**144 (±56)**	**73%**	**215 (±52)**	**71%**	**290 (±43)**	**66%**	**51**	**58%**	**24**	**48%**
Cascades	18 (±10)	92%	14 (±9)	63%	36 (±17)	78%	29 (±14)	85%				
Sierra Nevada					2 (±3)	100%						
Wasatch and Uinta Mountains	4 (±6)	93%	1 (±1)	68%								
Arizona/New Mexico Mountains	17 (±24)	61%										
Edwards Plateau			37 (±34)	66%	42 (±50)	49%	55 (±47)	54%	64	51%	51	47%
South Central Plains	**167 (±83)**	**72%**	**374 (±239)**	**70%**	**103 (±38)**	**48%**	**367 (±297)**	**86%**	**156**	**52%**	**115**	**53%**
Ouachita Mountains	**11 (±7)**	**62%**	**12 (±9)**	**69%**	**15 (±15)**	**91%**	**17 (±12)**	**87%**	**17**	**62%**	**9**	**60%**
Arkansas Valley					29 (±21)	41%					17	40%
Boston Mts.	3 (±3)	62%			4 (±3)	63%	4 (±3)	90%			5	52%
Ozark Highlands	112 (±121)	66%	42 (±33)	56%	61 (±42)	48%	55 (±38)	48%				
Canadian Rockies	3 (±3)	99%	4 (±3)	98%	2 (±2)	83%	5 (±3)	74%				
Piedmont	**980 (±895)**	**79%**	**503 (±201)**	**58%**	**1569 (±859)**	**70%**	**2263 (±1374)**	**73%**	**837**	**59%**	**269**	**52%**
Northern Minnesota Wetlands	5 (±5)	64%					1 (±1)	59%				
Northern Lakes and Plains	45 (±37)	97%	63 (±33)	85%	64 (±35)	89%	115 (±104)	94%				
Northeastern Highlands	**85 (±53)**	**83%**	**67 (±52)**	**84%**	**161 (±116)**	**91%**	**194 (±140)**	**69%**	**34**	**62%**	**29**	**55%**
Northeastern Coastal Zone	**223 (±73)**	**78%**	**162 (±44)**	**75%**	**368 (±85)**	**71%**	**369 (±83)**	**75%**	**214**	**60%**	**137**	**57%**
N. Appalachian Plateau and Uplands	24 (±15)	63%	11 (±11)	62%			19 (±12)	43%	4	43%		
Erie Drift Plains	67 (±36)	43%			137 (±77)	44%			53	45%		
North Central Appalachians	**7 (±5)**	75%	**16 (±11)**	83%	**27 (±17)**	82%	**27 (±14)**	90%	**6**	73%	**12**	68%

Table 1. *Cont.*

Ecoregion	Forest to Urban, 1973–1980, km²	Forest to Urban as % of Total New Developed 1973–1980	Forest to Urban, 1980–1986, km²	Forest to Urban as % of Total New Developed 1980–1986	Forest to Urban, 1986–1992, km²	Forest to Urban as % of Total New Developed 1986–1992	Forest to Urban, 1992–2000, km²	Forest to Urban as % of Total New Developed 1992–2000	Forest to Urban, 2001–2006, km²	Forest to Urban as % of Total New Developed 2001–2006	Forest to Urban, 2006–2011, km²	Forest to Urban as % of Total New Developed 2006–2011
Middle Atlantic Coastal Plain	444 (±270)	88%	498 (±336)	83%	493 (±305)	83%	306 (±178)	54%				
Southeastern Plains	483 (±325)	73%	578 (±367)	70%	578 (±330)	61%	1415 (±713)	69%				
Blue Ridge Mountains	**112 (±59)**	**95%**	**95 (±68)**	**94%**	**66 (±53)**	**61%**	**191 (±71)**	**94%**	**38**	**67%**	**17**	**55%**
Ridge and Valley	148 (±70)	60%	110 (±39)	41%	152 (±66)	47%	317 (±126)	46%	219	43%		
SW Appalachians	**14 (±7)**	**77%**	**61 (±50)**	**72%**	**56 (±29)**	**64%**	**92 (±42)**	**70%**	**23**	**42%**	**15**	**56%**
Central Appalachians	60 (±28)	59%	18 (±10)	65%	37 (±18)	40%	74 (±37)	61%			5	51%
Western Allegheny Plateau	**47 (±26)**	**74%**	**30 (±11)**	**56%**	**76 (±46)**	**53%**	**79 (±26)**	**47%**	**87**	**57%**	**38**	**48%**
Interior Plateau	105 (±73)	46%										
Mississippi Alluvial Plain	178 (±163)	50%	266 (±217)	47%			286 (±349)	41%				
North Cascades	1 (±2)	100%			3 (±3)	99%			3	47%		
Klamath Mountains							28 (±27)	51%				
Laurentian Plains and Hills	**17 (±9)**	**91%**	**18 (±9)**	**78%**	**25 (±12)**	**85%**	**49 (±20)**	**81%**	**11**	**60%**	**6**	**58%**
E Great Lakes and Hudson Lowlands	160 (±108)	64%	168 (±135)	62%			185 (±130)	42%				
Atlantic Coastal Pine Barrens	88 (±45)	45%	98 (±32)	41%					73	45%	45	45%

3. Results

A plurality of the ecoregions (35 out of 84) had conditions where at least 40% of their new developed land cover came from upland forest land cover at least one time during the study period. Geographically, these ecoregions tended to be clustered in the eastern U.S. outside of Florida (Figure 3). Other large regional clusters include the Pacific Northwest, the South-central U.S., and the Great Lakes North Woods as well as the "Texas Hill country" (Edwards Plateau, ecoregion #30 in Figure 1) and scattered ecoregions across the Inter-Mountain West, although most of the ones there were infrequent in occurrence. A number of these 35 ecoregions also had small area amounts of land being converted to developed land cover from forest (Table 1), making them appear more impressive on a map based on percentage of overall newly urban developed land than area affected.

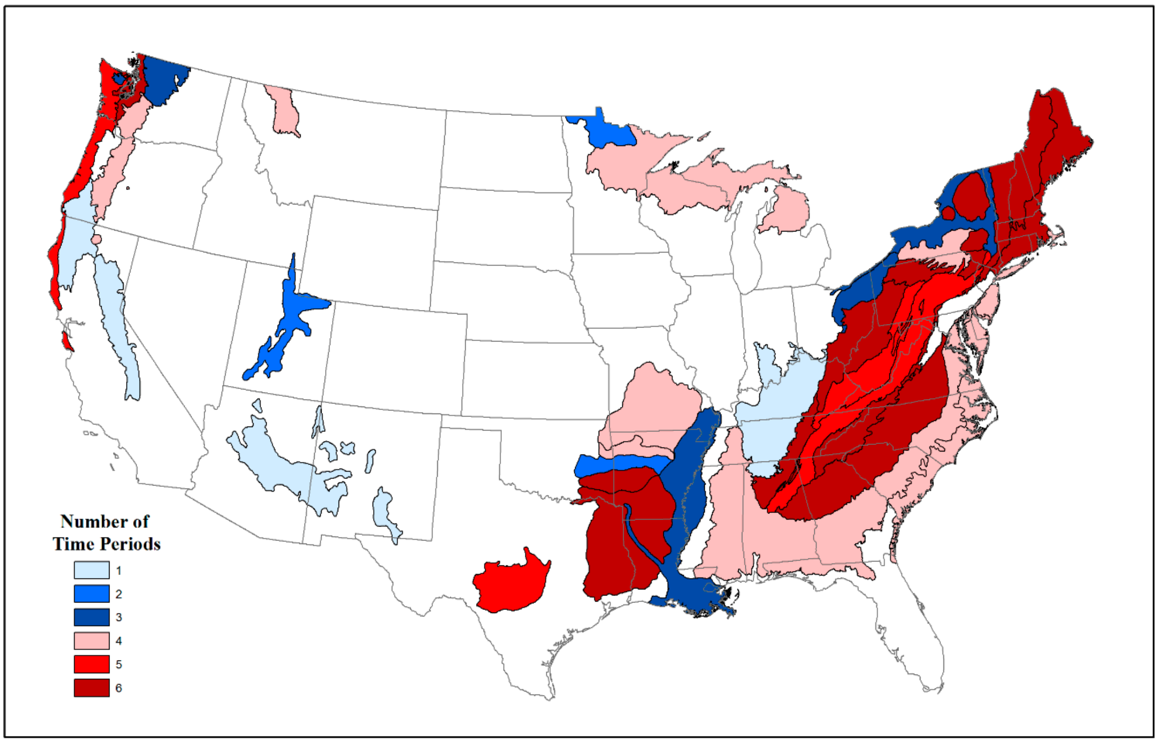

Figure 3. Ecoregions with forest as a substantial source of new development in any and all time intervals. Ecoregions where at least 40% of new developed land cover came from forest.

The number of ecoregions where forest was the source of at least 40% of the new urban development in every time period was more limited (11 out of 84). The number of clusters shrunk as well with only the Puget Lowland (ecoregion #2 in Figure 1) found in the Western U.S., a two-ecoregion cluster in the South-central U.S., three ecoregions in the Northeast, and five ecoregions scattered across the Appalachian Mountains and foothills (Figure 3). The Piedmont, Northeastern Coastal Zone, Puget Lowlands, and South Central Plains (ecoregions #45, #59, #2, and #35, respectively, in Figure 1) consistently had the most forest to urban developed land cover by area across time.

A majority of the ecoregions (58 out of 84) had at least one time interval where the proportion of forest to urban development in overall new urban land exceeded the proportion of forest land cover within the ecoregion. This is a useful metric because it can indicate where forested land is targeted more for conversion than other land covers within an ecoregion, and without replacement from another land cover forested land may face noticeable losses. The geographic pattern was more widespread and diffuse (Figure 4) than that seen in the forest as a substantial source of new urban developed land cover (Figure 3). However, in many ecoregions where this metric occurred, the threshold was met only occasionally (Table 2).

Table 2. Ecoregions exceeding their proportion of forest in forest to developed land cover change in any and all time intervals (all time intervals in bold). Ecoregions where the proportion of forest to developed exceeded the proportion of forest found within the ecoregion.

Ecoregion	% Forest to Urban, 1973–1980, LC Trends	% Forest to Ecoregion, 1973–1980, LC Trends	% Forest to Urban, 1980–1986, LC Trends	% Forest to Ecoregion, 1980–1986, LC Trends	% Forest to Urban, 1986–1992, LC Trends	% Forest to Ecoregion, 1986–1992, LC Trends	% Forest to Urban, 1992–2000, LC Trends	% Forest to Ecoregion, 1992–2000, LC Trends	% Forest to Urban, 2001–2006, NLCD	% Forest to Ecoregion, 2001–2006, NLCD	% Forest to Urban, 2006–2011, NLCD	% Forest to Ecoregion, 2006–2011, NLCD
Coast Range							72.0	71.7				
Puget Lowland	**85.5**	**55.5**	**73.0**	**53.0**	**70.7**	**50.0**	**66.2**	**47.6**	**58.4**	**42.9**	**48**	**41.2**
Cascades	99.0	81.8					85.3	81.7				
Sierra Nevada					100.0	72.8						
S. California Mountains			28.9	27.3								
MT Valley & Foothill Prairies					35.8	17.8						
Wyoming Basin											5	2.4
Wasatch and Uinta Mts.	92.8	61.7	68.0	61.6								
Arizona/New Mexico Mountains	61	58										
Chihuahuan Deserts			4.2	2.4								
Western High Plains											0.7	0.5
Southwestern Tablelands											5.7	2.8
Central Great Plains									3.8	2.5	3.2	2.5
Flint Hills			16.3	6.1					13.7	5.6	10	5.6
Central Oklahoma/Texas Plains							23.7	19.3				
Edwards Plateau			66.4	27.9	49.4	27.5	54.3	27.1	51.4	24.5	46.4	23.9
Southern Texas Plains	11.1	5.4							1.5	1.1	2.8	1.1
Texas Blackland Prairies									15.9	12.1	16.3	11.9
East Central Texas Plains					35.1	31.3	32.6	30.7	29.5	20.6	24.6	20.3
Western Gulf Coastal Plain	**21.2**	**12**	**12.7**	**11.9**	**21.5**	**11.9**	**28.3**	**11.7**	**12.9**	**5**	**11.3**	**4.8**
South Central Plains	72.4	62.7	69.9	60.6			85.9	59.3	51.8	47.2	52.8	45.8
Ouachita Mountains					90.5	76.9	86.8	78.5				
Boston Mts.							89.9	76.2				
Ozark Highlands	66.2	58.1										
Canadian Rockies	98.6	70.2	98.2	70.2	82.9	69.6	74.5	68.8				
Nebraska Sandhills									1.0	0.4	2.2	0.4

Table 2. *Cont.*

Ecoregion	% Forest to Urban, 1973–1980, LC Trends	% Forest to Ecoregion, 1973–1980, LC Trends	% Forest to Urban, 1980–1986, LC Trends	% Forest to Ecoregion, 1980–1986, LC Trends	% Forest to Urban, 1986–1992, LC Trends	% Forest to Ecoregion, 1986–1992, LC Trends	% Forest to Urban, 1992–2000, LC Trends	% Forest to Ecoregion, 1992–2000, LC Trends	% Forest to Urban, 2001–2006, NLCD	% Forest to Ecoregion, 2001–2006, NLCD	% Forest to Urban, 2006–2011, NLCD	% Forest to Ecoregion, 2006–2011, NLCD
Piedmont	78.6	59.4			70.4	57.2	72.6	55.8	59.4	57.3		
Northern Glaciated Plains			3.3	3.0					1.2	1.1		
Western Corn Belt Plains			5.4	3.3	4	3.3					6.2	4.4
Lake Agassiz Plain			6.3	5.6								
Northern Minnesota Wetlands	63.9	38.2					59.5	36.5	21.4	13.0		
Northern Lakes and Forests	97.3	64.1	84.5	63.2	88.6	62.4	94.4	61.9				
Southeastern Wisconsin Till Plains					15.5	11.9						
Central Corn Belt Plains	11	9.5	12.5	9.4					9.6	8.8	12.1	8.8
Eastern Corn Belt Plains					13.9	12.8			14.2	13.9		
S. Michigan/N. Indiana Drift Plains	33.4	24.4							23.0	20.1	20.3	20
Huron/Erie Lake Plains	**17.5**	**12.8**	**13.0**	**12.7**	**21.5**	**12.7**	**18.8**	**12.6**			**11.6**	**8.9**
Northeastern Highlands			83.9	83.1	91.3	81.9						
Northeastern Coastal Zone	**77.9**	**50.2**	**75.3**	**49.5**	**71.2**	**48.7**	**75.3**	**47.5**	**60.4**	**45.6**	**56.6**	**44.9**
N. Appalachian Plateau and Uplands	63.1	60.0	62.0	60.0								
Erie Drift Plains	43.0	37.5	38.0	37.4	44.0	37.2			45.3	37.5		
North Central Appalachians							90.4	86.7				
Middle Atlantic Coastal Plain	**88.5**	**34.7**	**82.7**	**33.5**	**84.3**	**32.6**	**54.2**	**32**	**30.7**	**18.9**	**29.4**	**17.4**
Northern Piedmont									35.9	30.4		
Southeastern Plains	73.3	52.6	70.4	51.9	60.6	51.8	69.3	51.9				
Blue Ridge Mountains	95.1	79.3	93.9	79			93.7	78.5				
Ridge and Valley	60.2	57.1										
Western Allegheny Plateau	74.3	64.3										
Interior Plateau	45.8	38.9										
Interior River Lowland									27.4	27	28.6	26.9

Table 2. *Cont.*

Ecoregion	% Forest to Urban, 1973–1980, LC Trends	% Forest to Ecoregion, 1973–1980, LC Trends	% Forest to Urban, 1980–1986, LC Trends	% Forest to Ecoregion, 1980–1986, LC Trends	% Forest to Urban, 1986–1992, LC Trends	% Forest to Ecoregion, 1986–1992, LC Trends	% Forest to Urban, 1992–2000, LC Trends	% Forest to Ecoregion, 1992–2000, LC Trends	% Forest to Urban, 2001–2006, NLCD	% Forest to Ecoregion, 2001–2006, NLCD	% Forest to Urban, 2006–2011, NLCD	% Forest to Ecoregion, 2006–2011, NLCD
Mississippi Alluvial Plain	**49.7**	**10.3**	**46.5**	**9.9**	**28.4**	**9.6**	**41.3**	**9.6**	**11.4**	**4.5**	**14.8**	**4.5**
Southern Coastal Plain	27.9	27.6	32.9	26.4	27.7	25.3	29.1	24.4				
Southern Florida Coastal Plain	35.6	2.8	21.2	2.7	14.9	2.6	9.9	2.6				
Northern Cascades	100.0	71.7			98.9	70.9	100.0	70.4				
Northern Basin and Range									3.0	1.7	2.1	1.6
Laurentian Plains and Hills	90.8	71.8	77.9	71.0	84.7	70.2	81.0	70.0				
E Great Lakes and Hudson Lowlands	62.4	39.3	62.5	39			42.2	38.9	39	34.2	34.4	34
Atlantic Coastal Pine Barrens	**44.7**	**23.1**	**40.9**	**22.5**	**25.8**	**22**	**25.7**	**21.7**	**44.6**	**25.5**	**45**	**24.9**

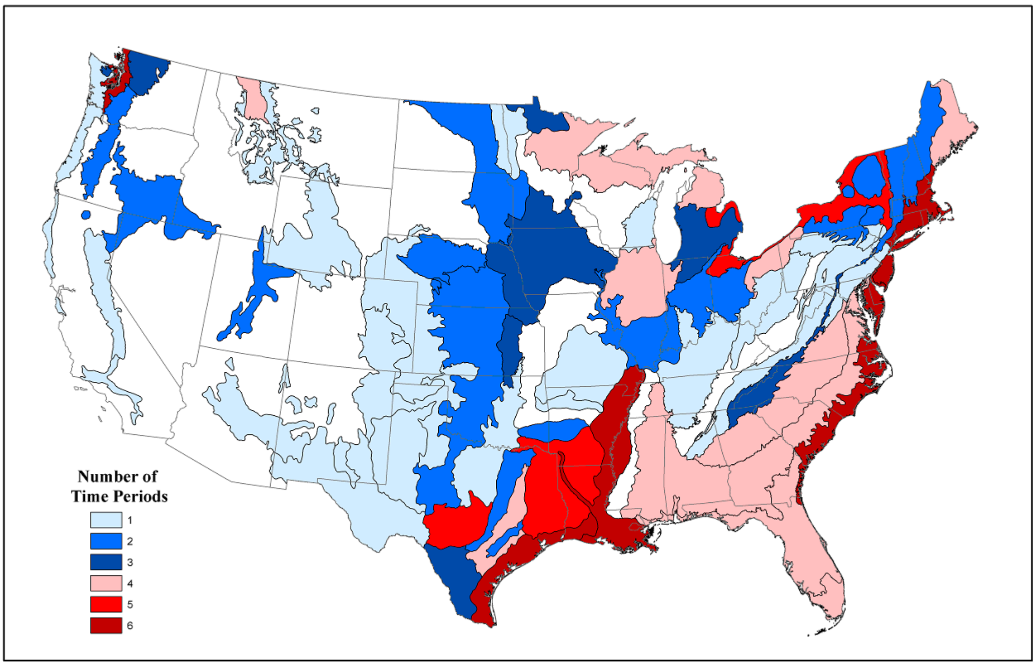

Figure 4. Ecoregions exceeding their proportion of forest in forest to urban developed land cover change in any and all time intervals. Ecoregions where the proportion of forest to developed land cover change exceeded the proportion of forest land cover found within the ecoregion.

The number of ecoregions where the proportion of forest to urban developed land cover change exceeded the proportion of forest within the ecoregion every interval was far fewer (6 out of 84,) than those exceeding it occasionally and only about half the ecoregions where forest was a substantial source of new urbanization every time interval. There was less geographic clustering of the six ecoregions that exceeded their proportion of forest every interval except the three along the eastern seaboard from southern Maine through Northern Florida (Figure 4), the Mississippi Alluvial Plain and Western Gulf Coastal Plain (ecoregions #73 and #34, respectively, in Figure 1), and the Puget Lowland (ecoregion #2 in Figure 1) in the Pacific Northwest. The six ecoregions that exceeded their forests' proportions when converting to urban development generally did so substantially.

Even though the annual rate of forest to developed land cover change was set at a fairly conservative number of 0.2%, only a minority of the ecoregions (12 out of 84) met or exceeded this rate at any time during the study period. Geographically, four clusters and one additional ecoregion are visible (Figure 5) although several of the clusters merge to create even larger contiguous regions. All of the ecoregions that front the Atlantic Ocean or Gulf of Mexico shoreline had a rate of 0.2% or greater annual change of upland forest converting to urban developed land cover at least once during the study period. Inland, the Northern Piedmont (ecoregion #64 in Figure 1) links highly urbanized areas of the Northeast coastal ecoregions and the Piedmont (ecoregion #45 in Figure 1) cities along the Fall Line and the foothills of the Appalachian Mountains, Gottmann's older "Megalopolis" of interspersed mosaics of urban, forest, and agricultural land covers [55] meeting up with Hart's and Morgan's emerging southern "Spersopolis" of low-density, but nearly continuous, residential housing along highways linking urban centers [56]. Another cluster is centered on the Erie Drift Plains and the Eastern Corn Belt Plains (ecoregions #61 and #55 respectively in Figure 1), whereas the Puget Lowland (ecoregion #2 in Figure 1) is the only ecoregion in the Western U.S.

The rate of "high" annual forest to urban developed land cover change ranged from three ecoregions reaching 0.2% at least during one time interval to the Southern Florida Coastal Plain (ecoregion #76 in Figure 1) reaching 0.61% annually during the 1986 to 1992 interval (Table 3). This ecoregion exceeded or nearly exceeded 0.5% annual change during the first three intervals of the LC Trends era, although with forest to urban developed land cover change declining to near zero during the NLCD intervals may bring into question the issue of how forest cover is classified as either "upland" or "wetland" between the two datasets. The Atlantic Coastal Pine Barrens (ecoregion #84 in Figure 1), which includes the center of the New York metropolitan area, was the only ecoregion to reach or exceed the 0.2% annual rate during all the time intervals.

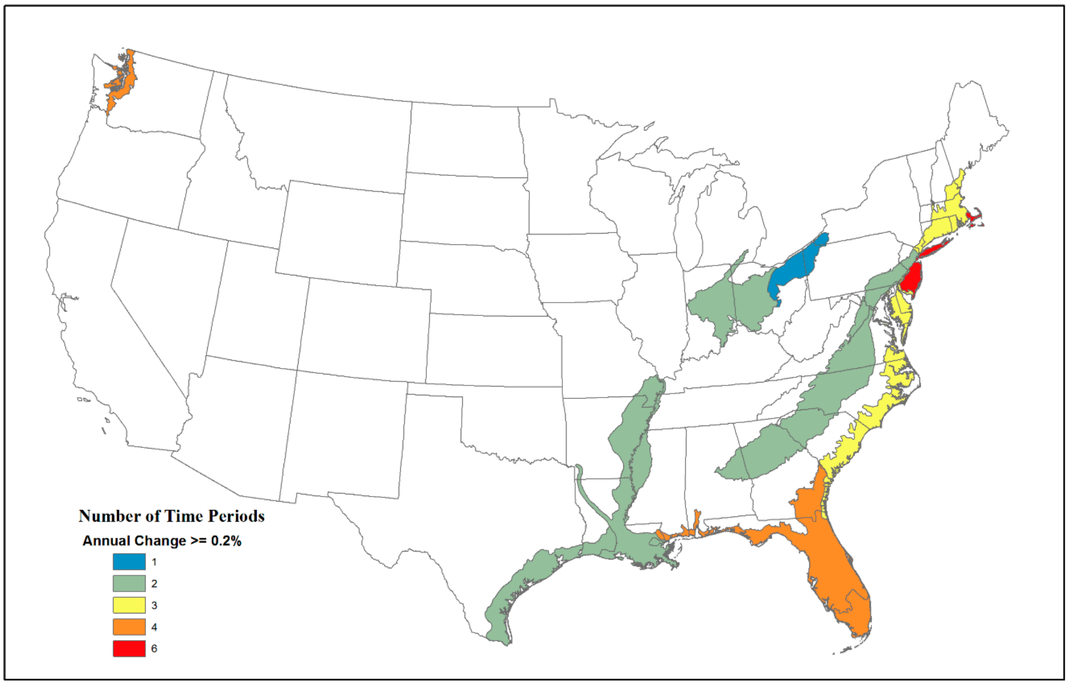

Figure 5. Ecoregions reaching or exceeding the rate of 0.2% annual forest to developed land cover change in any or all time intervals.

Table 3. Ecoregions reaching or exceeding the rate of 0.2% annual forest to developed land cover change in any or all time intervals (all time intervals in bold).

Eco	Annual Rate of Forest to Urban Change 73–80 LC Trends	Annual Rate of Forest to Urban Change 80–86 LC Trends	Annual Rate of Forest to Urban Change 86–92 LC Trends	Annual Rate of Forest to Urban Change 92–00 LC Trends	Annual Rate of Forest to Urban Change 01–06 NLCD	Annual Rate of Forest to Urban Change 06–11 NLCD
Puget Lowland	0.31%	0.25%	0.38%	0.42%		
Western Gulf Coastal Plain					0.26%	0.21%
Piedmont			0.27%	0.30%		
Eastern Corn Belt Plains			0.20%	0.24%		
Northeastern Coastal Zone			0.34%	0.26%	0.27%	
Erie Drift Plains			0.20%			
Middle Atlantic Coastal Plain	0.20%	0.27%	0.28%			
Northern Piedmont				0.25%	0.21%	
Mississippi Alluvial Plain		0.31%		0.26%		
Southern Coastal Plain	0.26%	0.26%	0.22%	0.27%		
Southern Florida Coastal Plain	0.56%	0.48%	0.61%	0.23%		
Atlantic Coastal Pine Barrens	0.28%	0.37%	0.24%	0.20%	0.35%	0.22%

The results of the composite metric shows that there are three ecoregions (Puget Lowland, Northeastern Coastal Zone, and the Atlantic Coastal Pine Barrens—ecoregions #2, #59, and #84, respectively, in Figure 1) that had 15 or above out of 18 "points" (Figure 6). Each of these are small ecoregions in size, heavily urbanized, and where continued urbanization has either been the leading or co-leading stories of land cover change during the study period.

Figure 6. Ecoregions with a composite forest to urban developed land cover change score of 15 or greater. Puget Lowland and Atlantic Coastal Pine Barrens (ecoregions #2 and #84, respectively, in Figure 1) both had a score of 16, whereas the Northeastern Coastal Zone (ecoregion #59 in Figure 1) scored 15.

4. Discussion

Forest land cover across the U.S. is dynamic because of the geographic and temporal variability of many human and natural drivers including harvesting-replanting cycles (timber management), agricultural clearance or abandonment, natural disturbances, including wind throw, fire, and insects and disease, climate change and drought, as well as urbanization [1,44]. Monitoring and understanding these changes requires a long-term view. This analysis of the urban growth effects on regional forest land cover shows some of these long-term spatial dynamics.

Upland forest land cover at the ecoregion scale within a national context has not been heavily impacted by forest cover loss to urban development during the study period, and certainly not as cartographically displayed by Clement et al. [24] for the 2001–2006 interval. Small, already heavily urbanized ecoregions such as the Northeastern Coastal Zone and the Atlantic Coastal Pine Barrens of the northeast and the Puget Lowlands of the northwest U.S. may be the exceptions and may have been impacted the most. This does not mean that the loss in specific ecosystem services of former forested land, especially those services not found or found in greater amounts than in urban tree cover, in moderately affected ecoregions should be overlooked or discounted in importance. Land-cover modeling efforts for future dates, such as 2050, or even 2100, show sustained losses of forest land cover to urban development at both regional [57] and national scales [58]. Research into the quantification of ecosystem services provided by undeveloped forest land cover should continue to be encouraged. The growth or maintenance of urban forests may mitigate and moderate some of the loss of undeveloped forested lands in various ecosystems services, but do they truly replace their undeveloped counterparts in all aspects? Multi-scale land-use policies protecting more forest or slowing the rates of conversion may need to be augmented or even created, depending on location, to balance forest land cover ecosystem services with the opportunities and amenities found in urban regions. These multi-scale forest retention land-use policies may have special relevance because most people in the U.S. and, increasingly, around the world, live in cities for specific reasons. Increased forest land-cover preservation may clash with efforts to protect farmland and other natural or non-built-up land covers and land uses because urban areas continue to expand in size even with the efforts to increase density within existing developed land cover [24]. Americans have long pushed the boundaries of their cities and it is something not easily culturally undone [47,59,60]. The dilemma on how best to keep the most undeveloped land covers from being converted to highly urbanized conditions while cities expand in size will not be easily solved and will remain an issue into the future.

A way to improve the multi-scale regionalization of mapping forest to urban developed land cover conversion may be the use of Level IV ecoregions using available multi-date wall-to-wall land cover datasets. Drummond et al. [61] used this scale for the 2001–2006 era within two Level III ecoregions in the Southeast U.S. and showed urban growth at a finer scale without losing the next scale up in geographic size. Forested land preservation planning may be better articulated and discussed using the results from land change mapping using multi-scale ecoregions that commonly cross local and even state political jurisdictions. The impacts of land cover change from individual or multiple urban areas may be seen more clearly using Level IV ecoregions and wall-to-wall land cover data.

The inclusion of forested wetland land cover change to urban developed land may be a way to provide a more comprehensive overview of forested land conversion to urban areas especially in the Southeast coastal region of the U.S. where Xian et al. [54] reported that "woody wetlands" was a leading source of newly urbanized land cover. This has not been the case in other ecoregions, such as the Northeastern Coastal Zone, where wetlands conversion to urban developed land cover was a minor source of increased urbanization [62]. The inclusion of Anderson II "woody wetlands" with current and future wall-to-wall land cover mapping would negate the issue of whether forest is correctly classified as "upland" or "wetland" and provide a better indication of the total contribution of "forest" land cover as a source of new urban land.

5. Conclusions

This study was able to show which ecoregions in the CONUS that have been heavily impacted by the conversion of forest to urban developed land and those less affected. Forest land cover is an important component of the land conversion story of increased urbanization. In the past, forest often was a "leftover" part of the anthropogenic landscape or returned to forest after being used for other uses such as agriculture or mining. There is an increasing realization that forest land cover provides needed ecosystem services within and surrounding built-up areas. Increased human population and climate change impacts, both drive the need to better understand the overall, multi-scale geographic nature of such land cover change. Advances in remote sensing capabilities to produce more accurate and temporal dense land cover maps, along with the needed analysis and knowledge dissemination of what is learned from such information, will help us keep up with a dynamic world.

Supplementary Materials: The calculations and steps performed for Tables 1–3 can be found in the "LC Trends and NLCD" Excel. The steps in scaling up from the multiple NLCD Anderson II forest and developed classes to single Anderson I class each for forest and developed can be found in the "NLCD Classes to LC Trends Classes" Excel. These Excels are available online at www.mdpi.com/link.

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Abbreviations

The following abbreviations are used in this manuscript:

MDPI	Multidisciplinary Digital Publishing Institute
DOAJ	Directory of open access journals
TLA	Three letter acronym
LD	linear dichroism

References

1. Sleeter, B.M.; Sohl, T.L.; Loveland, T.R.; Auch, R.F.; Acevedo, W.; Drummond, M.A.; Sayler, K.L.; Stehman, S.V. Land-cover change in the conterminous United States from 1973 to 2000. *Global Environ. Chang.* **2013**, *23*, 733–748. [CrossRef]
2. Seto, K.C.; Shepherd, J.M. Global urban land-use trends and climate impacts. *Curr. Opin. Environ. Sustain.* **2009**, *1*, 89–95. [CrossRef]
3. DeFries, R.S.; Rudel, T.; Uriart, M.; Hansen, M. Deforestation driven by urban population growth and agricultural trade in the twenty-first century. *Nat. Geosci.* **2010**, *3*, 178–181. [CrossRef]
4. Delphin, S.; Escobedo, F.J.; Abd-Elrahman, A.; Cropper, W.P. Urbanization as a land use change driver of forest ecosystem services. *Land Use Policy* **2016**, *54*, 188–199. [CrossRef]
5. Seto, K.C.; Fragkias, M.; Güneralp, B.; Reilly, M.K. A meta-analysis of global urban land expansion. *PLoS ONE* **2011**, *6*, e23777. [CrossRef] [PubMed]
6. Bounoua, L.; Zhang, P.; Mostovoy, G.; Thome, K.; Masek, J.; Imhoff, M.; Shepherd, M.; Quattrochi, D.; Santanello, J.; Silva, J. Impact of urbanization on US surface climate. *Environ. Res. Lett.* **2015**, *10*, 084010. [CrossRef]
7. Bagan, H.; Yamagata, Y. Land-cover change analysis in 50 global cities by using a combination of Landsat data and analysis of grid cells. *Environ. Res. Lett.* **2014**, *9*, 064015. [CrossRef]
8. Reinmann, A.B.; Hutyra, L.R.; Trlica, A.; Olofsson, P. Assessing the global warming potential of human settlement expansion in a mesic temperate landscape from 2005 to 2050. *Sci. Total. Environ.* **2016**, *545–546*, 512–524. [CrossRef] [PubMed]
9. Seto, K.C.; Güneralp, B.; Hutyra, L.R. Global forecasts of urban expansion to 2030 and direct impacts on biodiversity and carbon pools. *Proc. Natl. Acad. Sci. USA* **2012**, *109*, 16083–16088. [CrossRef] [PubMed]
10. Weber, T.; Sloan, A.; Wolf, J. Maryland's Green Infrastructure Assessment: Development of a comprehensive approach to land conservation. *Landsc. Urban Plan.* **2006**, *77*, 94–110. [CrossRef]
11. Gill, S.E.; Handley, J.F.; Ennos, A.R.; Pauleit, S.; Theuray, N.; Lindley, S.J. Characterising the urban environment of UK cities and towns: A template for landscape planning. *Landsc. Urban Plan.* **2008**, *87*, 210–222. [CrossRef]
12. Guo, X.; Li, W.; Da, L. Near-natural silviculture: Sustainable approach for urban renaturalization? Assessment based on 10 years recovering dynamics and eco-benefits in Shanghai. *J. Urban Plan. Dev.* **2015**, *141*. [CrossRef]
13. Salvati, L. Agro-forest landscape and the 'fringe' city: A multivariate assessment of land-use changes in a sprawling region and implications for planning. *Sci. Total. Environ.* **2014**, *490*, 715–723. [CrossRef] [PubMed]
14. Shifley, S.R.; Moser, W.K.; Nowak, D.J.; Miles, P.D.; Butler, B.J.; Aguilar, F.X.; Desantis, R.D.; Greenfield, E.J. Five anthropogenic factors that will radically alter forest conditions and management needs in the Northern United States. *For. Sci.* **2014**, *60*, 914–925. [CrossRef]
15. Millennium Ecosystem Assessment. *Ecosystems and Human Well-Being: A Framework for Assessment*; Island Press: Washington, DC, USA, 2005.
16. Ye, Y.; Zhang, J.E.; Chen, L.; Ouyang, Y.; Parajuli, P. Dynamics of ecosystem services values in response to landscape pattern changes from 1995 to 2005 in Guangzhou, Southern China. *Appl. Ecol. Environ. Res.* **2015**, *13*, 21–36.
17. Wu, Y.; Li, S.; Yu, S. Monitoring urban expansion and its effects on land use and land cover changes in Guangzhou city, China. *Environ. Monit. Assess.* **2016**, *188*, 1–15. [CrossRef] [PubMed]
18. Xian, G.; Crane, M. Assessments of urban growth in the Tampa Bay watershed using remote sensing data. *Remote. Sens. Environ.* **2005**, *97*, 203–215. [CrossRef]
19. Xian, G.; Crane, M.; McMahon, C. Quantifying multi-temporal urban development characteristics in Las Vegas from Landsat and ASTER data. *Photogramm. Eng. Remote. Sens.* **2008**, *74*, 473–481. [CrossRef]

20. Jeon, S.B.; Olofsson, P.; Woodcock, C.E. Land use change in New England: A reversal of the forest transition. *J. Land Use Sci.* **2014**, *9*, 105–130. [CrossRef]
21. Wu, Y.-J.; Thomas, V.; Oliver, R. Forest change dynamics across levels of urbanization in the eastern United States. *Southeast. Geogr.* **2014**, *54*, 406–420. [CrossRef]
22. Kennedy, R.E.; Yang, Z.; Braaten, J.; Copass, C.; Natalya, A.; Jordan, C.; Nelson, P. Attribution of disturbance change agent from Landsat time-series in support of habitat monitoring in the Puget Sound region, USA. *Remote. Sens. Environ.* **2015**, *166*, 271–285. [CrossRef]
23. Jiang, Y.; Fu, P.; Weng, Q. Assessing the impacts of urbanization-associated land use/land cover change on land surface temperature and surface moisture: A case study in the Midwestern United States. *Remote. Sens.* **2015**, *7*, 4880–4898. [CrossRef]
24. Clement, M.T.; Chi, G.; Ho, H.C. Urbanization and land-use change: A human ecology of deforestation across the United States, 2001–2006. *Sociol. Inq.* **2015**, *85*, 628–653. [CrossRef]
25. Omernik, J.M. Ecoregions of the conterminous United States. *Ann. Assoc. Am. Geogr.* **1987**, *77*, 118–125. [CrossRef]
26. Omernik, J.M.; Griffith, G.E. Ecoregions of the conterminous United States: Evolution of a hierarchical spatial framework. *Environ. Manag.* **2014**, *54*, 1249–1266. [CrossRef] [PubMed]
27. Sletter, B.M., Wilson, T.S., Acevedo, W. (Eds.) Appendix 3. In *Status and Trends of Land Change in the Western United States—1973 to 2000*; U.S. Geological Survey Professional Paper 1794-A; U.S. Geological Survey: Reston, VA, USA, 2012; p. 317.
28. U.S. Geological Survey. National Land Cover Database 2006 (NLCD2006) Product Legend. 2016. Available online: http://www.mrlc.gov/nlcd06_leg.php (accessed on 11 May 2016).
29. Loveland, T.R.; Sohl, T.L.; Stehman, S.V.; Gallant, A.L.; Sayler, K.L.; Napton, D.E. A strategy for estimating the rates of recent United States land-cover changes. *Photogramm. Eng. Remote. Sens.* **2002**, *68*, 1091–1099.
30. Auch, R.F.; Drummond, M.A.; Sayler, K.L.; Gallant, A.L.; Acevedo, W. An approach to assess land cover trends in the conterminous United States (1973–2000). In *Remote Sensing and Land Cover: Principles and Applications*; Giri, C., Ed.; Taylor and Francis CRC Press: Boca Raton, FL, USA, 2012; pp. 351–367.
31. U.S. Environmental Protection Agency. Level III Ecoregions of the Continental United States, 1999. National Health and Environmental Effects Research Laboratory, Scale 1:7,500,000 Map. 2015. Available online: ftp://ftp.epa.gov/wed/ecoregions/usgs/useco_March1999_v5.pdf (accessed on 26 March 2016).
32. Anderson, J.R.; Hardy, E.E.; Roach, J.T.; Witmer, R.E. *A Land use and Land Cover Classification System for Use with Remote Sensor Data*; U.S. Government Printing Office: Washington, DC, USA, 1976; p. 41.
33. Homer, C.G.; Dewitz, J.; Yang, L.; Jin, S.; Danielson, P.; Xian, G.; Coulston, J.; Herold, N.; Wickham, J.; Megown, K. Completion of the 2001 National Land Cover Database for the conterminous United States. *Photogramm. Eng. Remote. Sens.* **2007**, *73*, 337–341.
34. Vogelmann, J.E.; Howard, S.M.; Yang, L.; Larson, C.R.; Wylie, B.K.; van Driel, N. Completion of the 1990s National Land Cover Data Set for the conterminous United States from Landsat Thematic Mapper data and ancillary data sources. *Photogramm. Eng. Remote. Sens.* **2001**, *67*, 650–662.
35. Wickham, J.D.; Stehman, S.V.; Gass, L.; Dewitz, J.; Fry, J.A.; Wade, T.G. Accuracy assessment of NLCD 2006 land cover and impervious surface. *Remote. Sens. Environ.* **2013**, *130*, 294–304. [CrossRef]
36. Fry, J.; Xian, G.; Jin, S.; Dewitz, J.; Homer, C.; Yang, L.; Barnes, C.; Herold, N.; Wickham, J. Completion of the 2006 National Land Cover Database for the conterminous United States. *Photogramm. Eng. Remote. Sens.* **2011**, *77*, 858–864.
37. Homer, C.; Dewitz, J.; Yang, L.; Jin, S.; Danielson, P.; Xian, G.; Coulston, J.; Herold, N.; Wickham, J.; Megown, K. Completion of the 2011 National Land Cover Database for the conterminous United States—A decade of land cover change information. *Photogramm. Eng. Remote. Sens.* **2015**, *81*, 345–354.
38. Fry, J.; Coan, M.; Homer, C.; Meyer, D.; Wickham, J. Completion of the National Land Cover Database (NLCD) 1992–2001 Land Cover Change Retrofit Product. U.S. Geological Survey Open-File Report 2008-1379. Available online: http://pubs.usgs.gov/of/2008/1379/ (accessed on 17 May 2016).
39. Hollister, J.W.; Gonzalez, M.L.; Paul, J.P.; August, P.V.; Copeland, J.L. Assessing the accuracy of national land cover dataset area estimates at multiple spatial extents. *Photogramm. Eng. Remote. Sens.* **2004**, *70*, 405–414. [CrossRef]
40. Stehman, S.V.; Sohl, T.L.; Loveland, T.R. Statistical sampling to characterize recent United States land-cover change. *Remote. Sens. Environ.* **2003**, *86*, 517–529. [CrossRef]

41. Griffith, J.A.; Stehman, S.V.; Sohl, T.L.; Loveland, T.R. Detecting trends in landscape pattern metrics over a 20-year period using a sampling-based monitoring programme. *Int. J. Remote. Sens.* **2003**, *24*, 175–181. [CrossRef]
42. Stehman, S.V.; Sohl, T.L.; Loveland, T.R. Statistical sampling to characterize recent United States land-cover change. *Int. J. Remote. Sens.* **2005**, *26*, 4941–4957. [CrossRef]
43. Sleeter, B.M. Late 20th century land change in the Central California Valley Ecoregion. *Calif. Geogr.* **2008**, *48*, 27–60.
44. Drummond, M.A.; Loveland, T.R. Land-use pressure and a transition to forest-cover loss in the eastern United States. *BioScience* **2010**, *60*, 286–298. [CrossRef]
45. Napton, D.E.; Auch, R.F.; Headley, R.; Taylor, J.L. Land changes and their driving forces in the south eastern United States. *Reg. Environ. Chang.* **2010**, *10*, 37–53. [CrossRef]
46. Auch, R.F.; Sayler, K.L.; Napton, D.E.; Taylor, J.L.; Brooks, M.S. Ecoregional differences in late-20th-century land-use and land-cover change in the U.S. northern great plains. *Great Plains Res.* **2011**, *21*, 231–243.
47. Auch, R.F.; Napton, D.E.; Kambly, S.; Moreland, T.R., Jr.; Sayler, K.L. The driving forces of land change in the northern piedmont of the United States. *Geogr. Rev.* **2012**, *102*, 53–75. [CrossRef]
48. Soulard, C.E.; Sletter, B.M. Late twentieth century land-cover change in the basin and range ecoregions of the United States. *Reg. Environ. Chang.* **2012**, *12*, 813–823. [CrossRef]
49. Drummond, M.A.; Auch, R.F.; Karstensen, K.A.; Sayler, K.L.; Taylor, J.L.; Loveland, T.R. Land change variability and human-environment dynamics in the United States Great Plains. *Land Use Policy* **2012**, *29*, 710–723. [CrossRef]
50. Sohl, T.L.; Sohl, L.B. Land-sue change in the Atlantic coastal pine barrens ecoregion. *Geogr. Rev.* **2012**, *102*, 180–201. [CrossRef]
51. Soulard, C.E.; Wilson, T.S. Recent land-use/land-cover change in the Central California Valley. *J. Land Use Sci.* **2015**, *10*, 59–80. [CrossRef]
52. Auch, R.F.; Napton, D.E.; Sayler, K.L.; Drummond, M.A.; Kambly, S.; Sorenson, D.G. The Southern Piedmont's continued land-use evolution, 1973–2011. *Southeast. Geogr.* **2015**, *55*, 338–361. [CrossRef]
53. Wickham, J.D.; Riitters, K.H.; Wade, T.G.; Coan, M.; Homer, C. The effect of Appalachian mountaintop mining on interior forest. *Landsc. Ecol.* **2007**, *22*, 179–187. [CrossRef]
54. Xian, G.; Homer, C.; Bunde, B.; Danielson, P.; Dewitz, J.; Fry, J.; Pu, R. Quantifying urban land cover change between 2001 and 2006 in the Gulf of Mexico region. *Geocarto Int.* **2012**, *27*, 479–497. [CrossRef]
55. Gottmann, J. *Megalopolis: The Urbanized Northeastern Seaboard of the United States*; Twentieth Century Fund: New York, NY, USA, 1961; p. 820.
56. Hart, J.F.; Morgan, J.T. Spersopolis. *Southeast. Geogr.* **1995**, *35*, 103–117. [CrossRef]
57. Terando, A.J.; Costanza, J.; Belyea, C.; Dunn, R.R.; McKerrow, A.; Collazo, J.A. The southern megalopolis: Using the past to predict the future urban sprawl in the Southeast U.S. *PLoS ONE* **2014**, *9*, e102261. [CrossRef] [PubMed]
58. Sohl, T.L.; Sleeter, B.M.; Zhu, Z.; Sayler, K.L.; Bennett, S.; Bouchard, M.; Reker, R.; Hawbaker, T.; Wein, A.; Liu, S.; et al. A land-use and land-cover modeling strategy to support a national assessment of carbon stocks and fluxes. *Appl. Geogr.* **2012**, *23*, 111–124. [CrossRef]
59. von Hoffman, A.; Fleckner, J. *The Historical Origins and Causes of Urban Decentralization in the United States*; Joint Center for Housing Studies, Harvard University: Cambridge, MA, USA, 2001; p. 35.
60. Auch, R.F.; Acevedo, W.; Taylor, J.L. The historical development of the Nation's urban areas. *Rates, Trends, Causes, and Consequences of Urban Land-Use Change in the United States*; Acevedo, W., Taylor, J.L., Hester, D.J., Mladinich, C.S., Glavac, S., Eds.; U.S. Government Printing Office: Washington, DC, USA, 2006; pp. 1–12.
61. Drummond, M.A.; Stier, M.P.; Auch, R.F.; Taylor, A.; Griffith, G.E.; Hester, D.J.; Riegle, J.L.; Soulard, C.E.; Mcbeth, J.L. Assessing landscape change and processes of recurrence, replacement, and recovery in the Southeastern Coastal Plains, USA. *Environ. Manag.* **2015**, *56*, 1252–1271. [CrossRef] [PubMed]
62. Auch, R.F. Northeastern Coastal Zone. U.S. Geological Survey Land Cover Trends project web site. 2006. Available online: http://landcovertrends.usgs.gov/east/eco59Report.html (accessed on 26 March 2016).