Analyzing Forest Fragmentation in the Delaware River Watershed, 2011—2100

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Introduction

Landscape Ecology focuses on understanding landscape heterogeneity and how it influences organisms, populations, and ecosystems (Turner and Gardner, 2015), and fragmentation has played a central role in this approach. Habitat fragmentation is defined as the process where a habitat in the landscape is divided into smaller and increasingly isolated patches. It can have important implications on habitat quality relating to population viability and the organization and functioning of communities and natural ecosystems (Didham, et al, 2012). This process is usually driven by habitat loss and it is accepted that human activities and the dynamics of change in land use, and in particular the expansion of urban land and energy infrastructure, play a main role in driving landscape change and forest fragmentation in the eastern United States.

Traditionally, fragmentation studies have focused on past changes, but rarely on future changes. In this study, we compare a set of landscape metrics related to fragmentation of forests in two future urban land cover change scenarios in the Delaware River watershed. The first scenario assumes a continuation of post-World War II patterns of urban decentralization ("urban sprawl"), with increasing population and commensurate urbanization occurring particularly along major road corridors. The second scenario assumes widespread adoption of "smart growth" policies, and future urbanization is forecasted to occur in more compact patterns close to consolidated urban or town centers. We also assess the impact of future energy infrastructure on forests by incorporating planned electricity transmission line construction.

100 forest landscapes were generated for each scenario, subtracting the urban forecasts obtained with SLEUTH (Clarke & Gaydos, 1997) and the future energy infrastructure from the current forest extension. The analysis of patch distributions in three physiographic regions (Upper Delaware, Piedmont, and Coastal Plain) shows a common denominator: a large increase of patches smaller than 1 hectare, while the distribution of the rest of sizes remains invariable.

The analysis of landscape metrics in the landscape and development intensity range for the Piedmont region confirms the difficulty in differentiating habitat loss from fragmentation per se. We tried to create an actual fragmentation space by synthesizing multiple metrics into principal components and visualizing how landscapes will move in this space under the changes imposed by the two scenarios. A preliminary view of the results indicates that there are probably some common fragmentation paths that are determined by the grade of heterogeneity during the transition from a homogeneous forested landscape to a fragmented, but still forest-dominant, landscape. As is expected, the "Smart Growth" scenario has a lower impact than the "Urban Sprawl" scenario, however at finer scales the resultant fragmentation is a consequence more of the intensity than the spatial pattern of development, and this is related to how SLEUTH simulates growth.

This work is the first approach for assessing future tendencies of forest fragmentation in the context of the project "How will forest ecosystems and hydrologic processes in the Delaware River Basin be affected by climate change and land cover change?" which explores how multiple stressors of climate change and land use/land cover (LULC) change will alter hydrologic systems and forest ecosystems in the Delaware River Basin (DRB). This project is funded by the Delaware Watershed Research Fund and aimed at generating useful tools to help researchers and conservation practitioners who are actively participating in the Delaware River Watershed Initiative (DRWI).

Methods

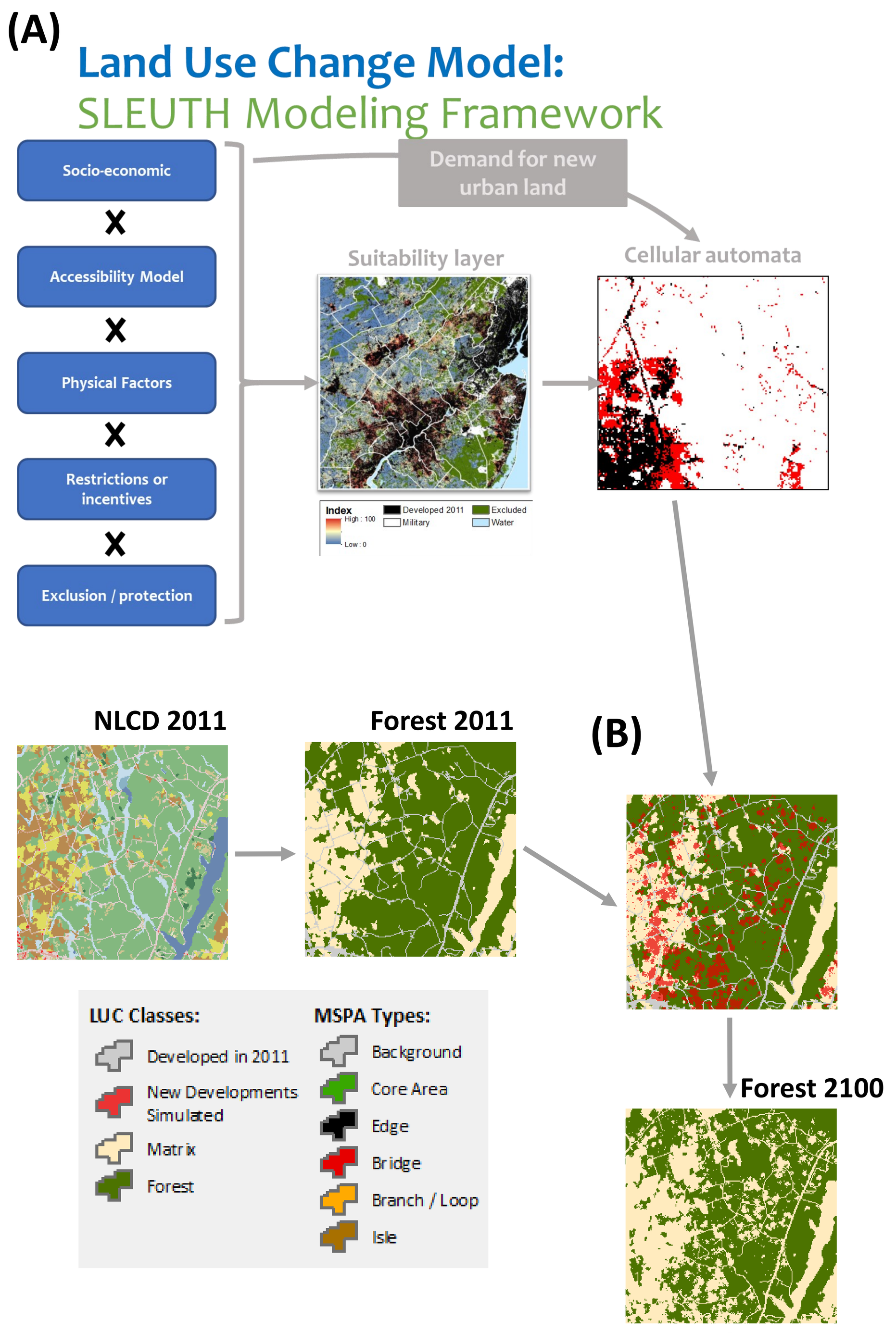


Figure 1A. The land use change model takes a multi-factor approach where different drivers and conditions are combined to create a suitability map. Two scenarios, "**Smart Growth**" and "**Urban Sprawl**" were created. Smart Growth is a conservative approach with lower population growth, development concentrated around centers, and maximum land protection. Urban Sprawl maintains the current development pattern with new development "sprawling" along transportation corridors. The suitability map is introduced into the stochastic model (SLEUTH) to generate 100 simulations of urban growth up to year 2100 for each scenario.

Figure 1B. NLCD 2011 was used to obtain the current forest extent and form the basis for future forest scenarios. Forest habitat was made up by the forest (41, 42, 43), shrub (51), and forested wetlands (90) NLCD classes. To create each future forest landscape, new developments are removed from the 2011 forest. Finally, morphological elements of the habitat were obtained by applying the Morphological Spatial Pattern Analysis (MSPA) software (Vogt & Riitters 2017). Fragstats v4 (McGarigal et al. 2012) was used to calculate fragmentation metrics of forest habitat and MSPA morphological types.

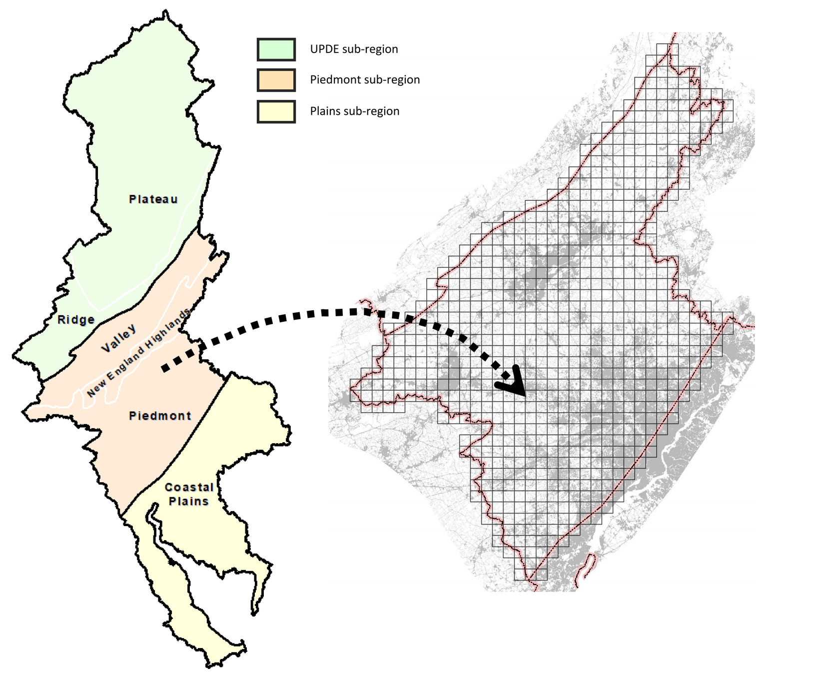
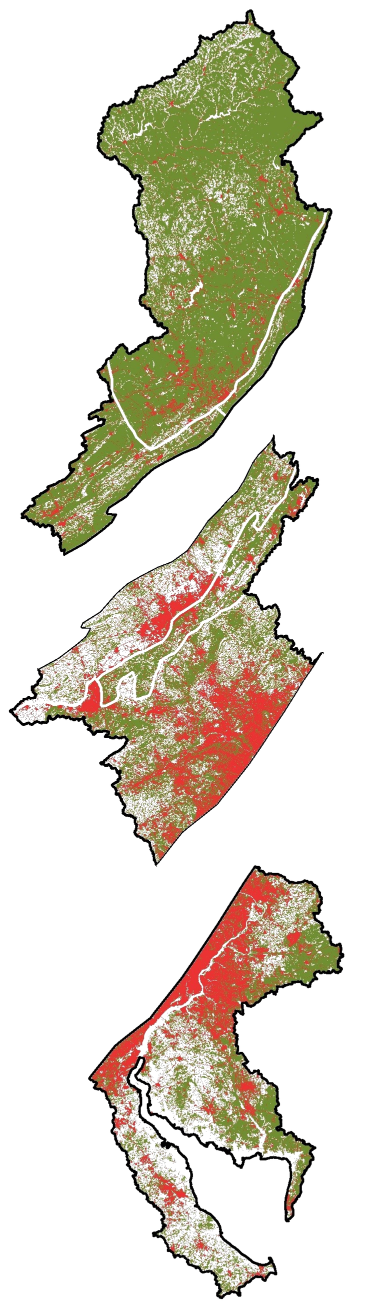


Figure 2. The area of study extends across the whole Delaware River Basin. We subdivided the basin in three sub-regions based on the topographic gradient. The northern region of the basin (**Upper Delaware**) is mountainous and dominated by forest landscapes, while to the south the portion of the **Coastal Plain** region in the watershed is identified. The **Piedmont** then occupies the central area, being the transition between the Upper Delaware and the Coastal Plain and is characterized by a diverse physiographic landscape and a fragmented mosaic of urban, agricultural and forest patches. Because of these characteristics, we focused specifically on the **Piedmont** to use PCA to describe fragmentation patterns. We subdivided the Piedmont subregion in tiles of 4x4 km, and summarized fragmentation characteristics for this array. We then used PCA to identify whether fragmentation patterns, as measured by multiple metrics, can be simply described with just a few principal components; and if those components logically relate to fragmentation patterns or process.

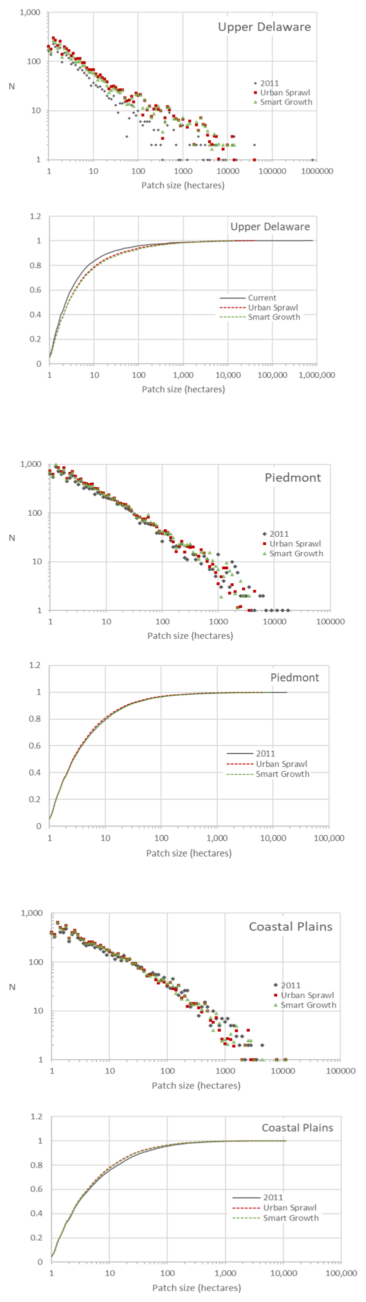
Results



UPPER DELAWARE	Current	Smart Growth	Urban Sprawl
New development (%)		1.24	3.33
Forest Abundance (km^2)	11,368 (*80.5%*)	***-2.27***	***-4.68***
Patches			
Total number	5594	*68.6*	*146.2*
Number small patches (< 1 ha)	2870	*101.0*	*236.8*
Prop. small patches	51.3	*9.9*	*18.9*
Largest Patch	7,968.26 km^2	*-84.1*	*-84.1*
Core Area			
Number of Cores	5,397	*66.5*	*104.0*
Prop. of total forest	68.4	*-8.8*	*-13.3*
Largest Core Area	942.68 km^2	*-27.1*	*-28.7*
Morphological changes			
Isle	101.54 km^2	*0.35*	0.65
Branch & Loops	607.5 km^2	*0.7*	0.72
Bridge	456.39 km^2	*3.04*	5.52
Edge	2,428.47 km^2	*4.59*	6.27
Core	7,774.38 km^2	*-8.68*	-13.16

PIEDMONT	Current	Smart Growth	Urban Sprawl
New development (%)		10.58	19.62
Forest Abundance (km^2)	4,098 (*37.9%*)	***-9.14***	***-17.72***
Patches			
Total number	21538	*72.1*	*116.7*
Number small patches (< 1 ha)	45.41	*142.2*	*235.1*
Prop. small patches	45.41	*18.5*	*24.8*
Largest Patch	1,906.46 km^2	*-51.6*	*-54.6*
Core Area			
Number of Cores	8,401	*1.5*	*-9.5*
Prop. of total forest	29.06	*-7.5*	*-9.6*
Largest Core Area	35.48 km^2	*-52.5*	*-54.8*
Morphological changes			
Isle	483.56 km2	*4.63*	7.73
Branch & Loops	544.86 km2	*-0.73*	-0.77
Bridge	564.3 km2	*5.43*	6.63
Edge	1314.38 km2	*-2.03*	-4.13
Core	1190.91 km2	*-7.3*	-9.46

PLAINS	Current	Smart Growth	Urban Sprawl
New development (%)		9.77	13.15
Forest Abundance (km^2)	11,368 (*80.5%*)	***-10.92***	***14.32***
Patches			
Total number	5594	*73.2*	*89.1*
Number small patches (< 1 ha)	2870	*160.2*	*196.7*
Prop. small patches	51.3	*21.3*	*24.2*
Largest Patch	7,968.26 km^2	*-2.8*	*-4.2*
Core Area			
Number of Cores	5,397	*-5.9*	*-6.0*
Prop. of total forest	68.4	*-8.6*	*-7.5*
Largest Core Area	942.68 km^2	*-4.3*	*-4.3*
Morphological changes			
Isle	306.29 km2	*4.7*	5.83
Branch & Loops	363.13 km2	*-0.87*	-1.12
Bridge	196.02 km2	*3.98*	4.54
Edge	860.23 km2	*-1.54*	-2.08
Core	968.21 km2	*-6.27*	-7.17



Landscape metrics have limitations for linking the spatial pattern they describe to ecological processes (Kupfer, 2012). To introduce a more functional approach, we focused on MSPA metrics such as "core," "bridge," and "isle," that emphasize the ecological role of the patch. The selection of the metrics also has to consider that fragmentation is tightly related to habitat loss, and selecting metrics with lower correlation to habitat abundance is recommended (Wang et al, 2014).

Table 4. Relation of metrics that were selected and calculated. The metrics in gray were considered but ultimately eliminated for the PCA analysis.

FRAGSTATS METRICS	Patch level	Class level	Landscape level
Area/Density/Edge	• Patch Area	• Percentage of Landscape* • Patch Area CV • Number of Patches* • **Normalized Landscape Shape Index**	
Shape		• Fractal Index CV	
Core Area		• Disjunct Core Areas • **Core Area AM, CV**	
Isolation/Proximity		• Proximity CV • Euclidean NN CV • **Core Proximity MN**** • Core Euclidean NN AM, CV**	
Connectivity		• Core Connectance	
Aggregation		• **Clumpiness**	
Diversity			• Simpson's Index**
MSPA Composition			• **Isle-Patch Proportion**** • **Bridge-Core Ratio****

* Metrics were calculated for both forest habitat and MSPA morphological types.

** Metrics were calculated only for MSPA morphological types.

No * metrics were calculated only for forest habitat.

Figures 3-5. Although there is an increment of patches the distribution of sizes greater than 1 hectare remains constant for all scenarios. Density distribution is in the upper graphic while cumulative distribution is in the lower.

Tables 1-3. Comparison of changes produced by both scenarios on patches, core area, and MSPA types. Colored values indicate the rate of change with respect to 2011 in percentage for absolute metrics while they are differences for relative metrics.

Figure 4. (A) A PCA analysis was performed with metrics calculated for the 777 tiles of the 2011 forest habitat. We tried to identify whether the variability of landscapes is organized into a couple of components with a logical fragmentation meaning. These components conform a "fragmentation space" and the arrangement of the landscapes in this space might show the presence of stages, gradients or groups. **(B)** The changes caused by one development simulation are shown by arrows. The chart highlights changes in both scenarios for ten selected landscapes, where color indicates the degree of habitat lost in each case.

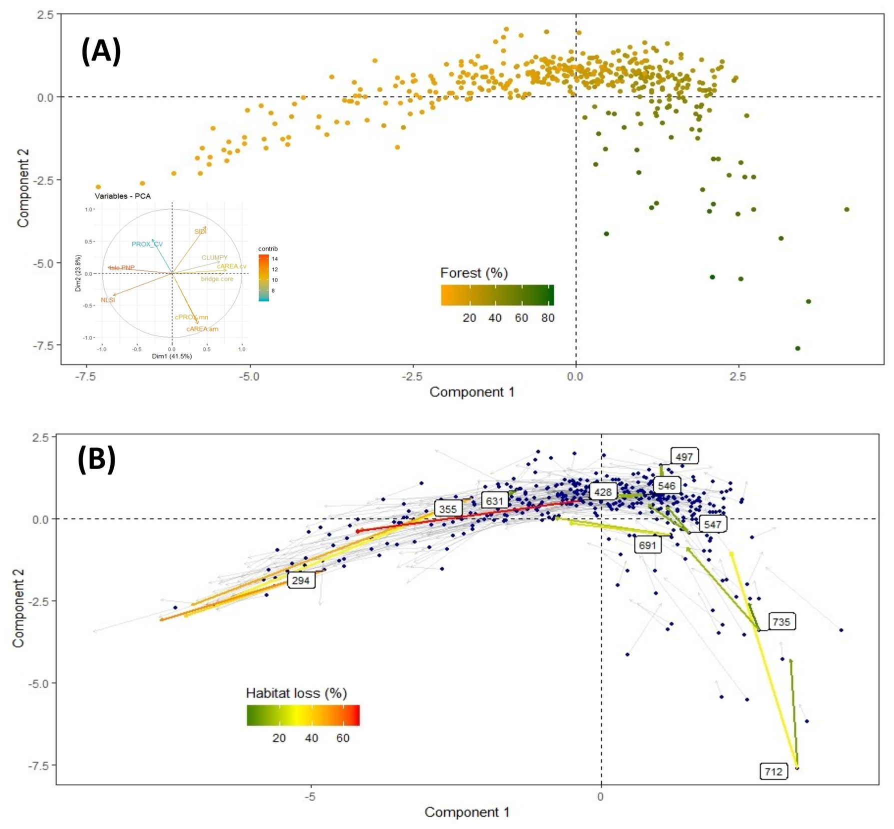
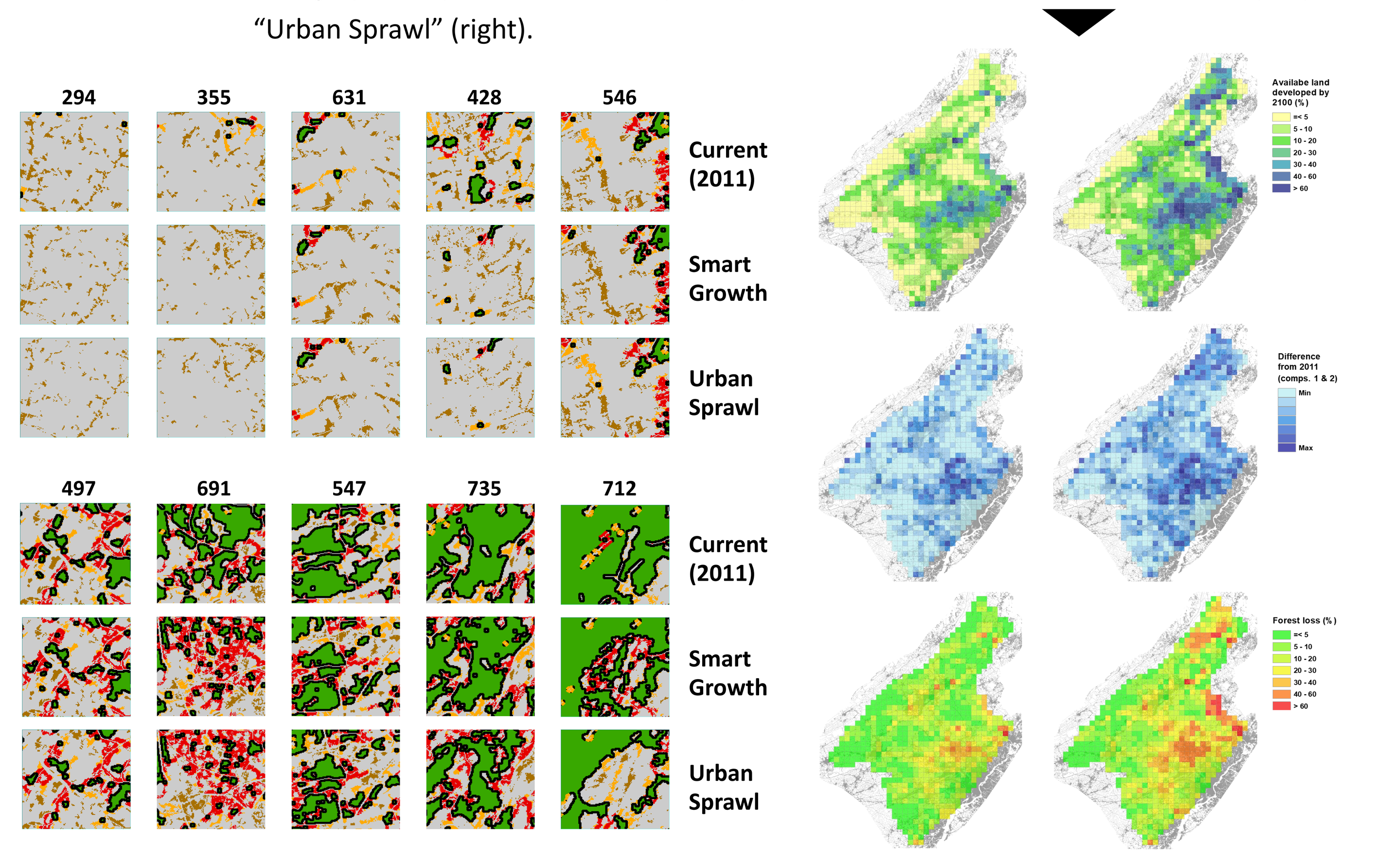


Figure 5. Distribution maps of Urban development intensity (upper), fragmentation change (middle) and habitat loss (lower) and for both scenarios, "Smart Growth" (left) and "Urban Sprawl" (right).



Conclusions

- Urban development and energy infrastructure operate at different scales, producing different change patterns depending on the landscape. Energy infrastructure manifests its effects over a broad scale perspective, splitting large patches; this is more evident and pronounced in the Upper Delaware sub-region. Urbanization operates at a local scale, increasing the amount of tiny patches dramatically. Differences between development scenarios are mainly due to the difference of the growth intensity and its spatial distribution at a medium scale (figure 5). However, both scenarios have the same spatial pattern in landscapes of 4x4 km. Impacts are exclusively related to the urban growth intensity, and this is due to the influence of how the urban simulation model (SLEUTH) works. SLEUTH's algorithm probably tends to generate more small patches.
- The results reveal the difficulty in differentiating fragmentation from habitat abundance, despite selecting metrics without a strong correlation to abundance. The two main fragmentation components are related to the core area. The first component shows the variation in the number of core patches, while the second is related with the size of cores. Landscapes are organized in this two-dimensional space, in what we can call the fragmentation path, which is tightly associated to the amount of habitat in the landscape (figure 4.A).
- Changes in the position of the landscape along this 'path' might indicate the degree of change in the fragmentation (figure 4.B). However, this raises new difficulties because, apparently, some landscape configurations at the ends of the 'path' are more sensitive to habitat loss.
- Difficulties for simplifying the measurement of the fragmentation change are a consequence of the fact that fragmentation may increase or decrease heterogeneity and many landscape indices show a divergent behavior from maximum heterogeneity, and because of the large spectrum of landscapes.
- This is a first approach to the problem, and future improvements must introduce more functional measures, connectivity, and a multiscale approach.

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