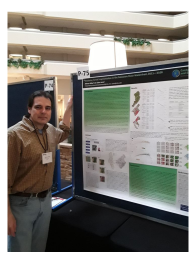
The effects of future urbanization and energy infrastructure expansion on forest fragmentation

Alfonso Yáñez Morillo and Claire Jantz

Center for Land Use and Sustainability, Shippensburg University

PRESENTED AT:

IALE - NORTH AMERICA
Brought to you by our Canadian Organizing Committee

2020 IALE-North America Annual Meeting
Virtual Remote Conference • May 11-14

INTRODUCTION

Introduction

The growth and expansion of the New York and Philadelphia metropolitan areas, two of the biggest and most populated in North America, highlights the importance and need to conserve the ecological systems in the Delaware River Basin (DRB).

Forests are essential to maintaining air and water quality; providing goods, recreational, and aesthetic opportunities; and serving as a refuge for wildlife. In an increasingly urban world, they are key elements for maintaining human health and quality of life. As urban areas expand in footprint and population, we see an increase of direct impacts on forests, so it would be desirable that future local and regional planning rely on the assessment of potential landscape changes.

Objective

Our objective is to analyze basin-wide changes in forest habitats, cover, and structure in the basinDelaware River Basin. Specifically, we

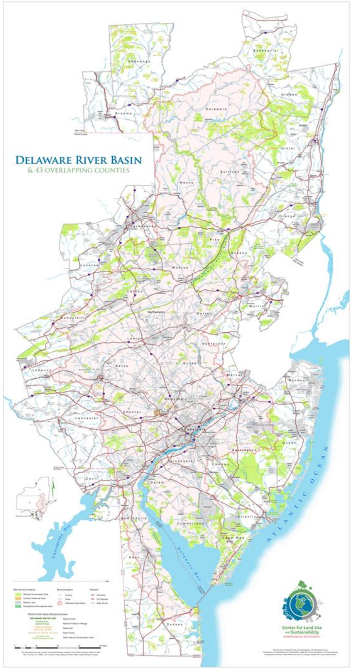
1. measure and locate expected forest loss and quantify the risk of habitat loss in 2100 related to a future urban development scenario; we also consider the impact of future energy infrastructure by incorporating planned electric transmission lines,
2. identify spatial configuration patterns and verify whether future patterns of change conform or contrast with existing ones, and
3. consider whether less fragmented landscapes are able to better absorb the effects of different habitat forest loss patterns or if they are more susceptible to drastic changes than more fragmented landscapes.

This work is part of a broader project called "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 aims to generating useful data and knowledge to help researchers and conservation practitioners who are actively participating in the Delaware River Watershed Initiative (DRWI).

Study Area

The area of study extends across the whole Delaware River Basin. The Delaware River Basin covers 13,500 square miles occupying parts of New York, New Jersey, Pennsylvania, and Delaware. The population in the basin is approximately 7.3 million people, although the basin provides water to over 15 million people, including 5 million in New York City.

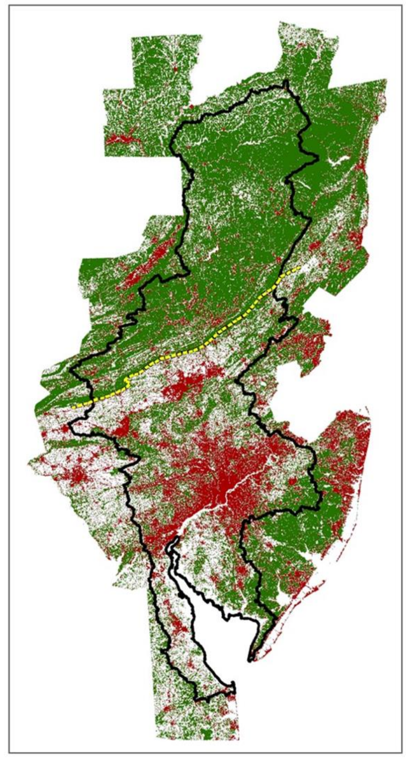
Forests are not even distributed in the basin. The Northern Kittatinny Ridge, the physiographic regions of Appalachian Plateau and Ridge and Valley, are dominated by forest landscapes. Here, forests make up 80 percent of the land while in the southern region they only represent 37 percent, mostly associated with the New England Highlands physiographic region or New Jersey's Pine Barrens in the Coastal Plains. The Piedmont and Coastal Plains are characterized by a gradient of urban-suburban-farmland landscapes with small forest patches remaining.



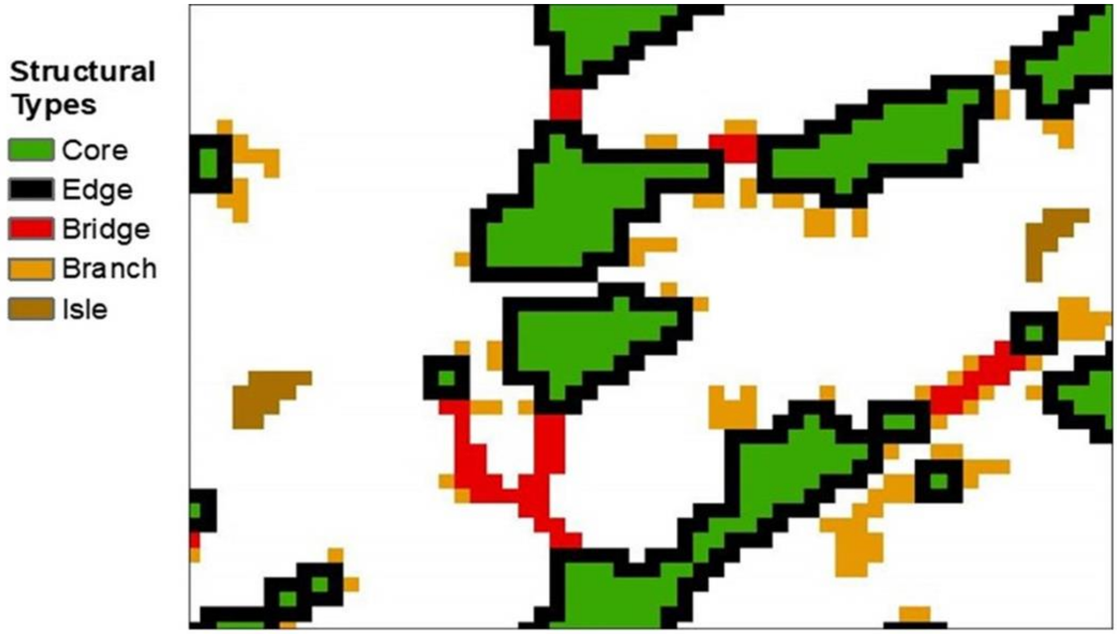
EFFECTIVE HABITAT DENSITY

Landscape metrics have limitations for linking the spatial pattern they describe to ecological processes (Kupfer, 2012). We think the equivalent area or ecological quality are useful concepts to fill this gap and we introduce a new metric based on those concepts to analyze fragmentation in this study.

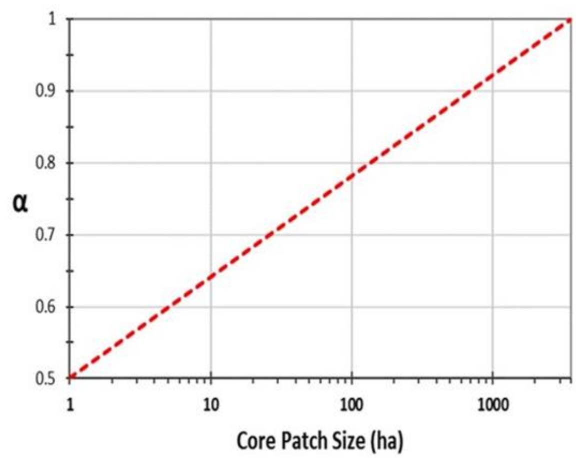
We define habitat quality as a function of the morphological structure of the habitat. To do it we used the structural types obtained with the Morphological Spatial Analysis (MSPA) from Guidos Tools software (Vogt & Ritters, 2017). The MSPA algorithm performs segmentation from habitat/non-habitat maps into several types describing size, shape, connectivity and spatial arrangement of habitat and matrix classes.



We weighted the structural types based on ecological criteria to translate spatial structure into habitat quality.



Structural Class	w_i
Core	$\begin{cases} \alpha_i = 0.14\ Log_{10}(s_i) + 0.5 \\ 1, \quad if\ s_i \geq 3{,}600\ ha \end{cases}$ where α_i is the weight assigned and s_i is size for core patch *i* in hectares.
Edge	0.45
Bridge	0.5
Branch, Loop	0.25
Islet	0.1



Weights for MSPA types give more importance to the elements closely related to core areas, assuming they represent the least disturbed habitat, and those connecting cores. We give less importance to those that increase edge or number of fragments. In addition, the weight coefficient for the core type is dependent on the core fragment size. The coefficient was determined by a linear relationship with the logarithm of the core patch size.

We define the ***Equivalent Habitat*** (Heq) as:

$$H_{eq} = \sum (A_i * w_i)$$

$\boldsymbol{A_i}$: area of structural type *i*,

$\boldsymbol{w_i}$: structural type i weight.

And ***Effective Habitat Density*** (EHD) as:

$$EHD = \frac{\sqrt{H_{eq}(H_{eq} + H)}}{4S}$$

H_{eq}: equivalent habitat area,

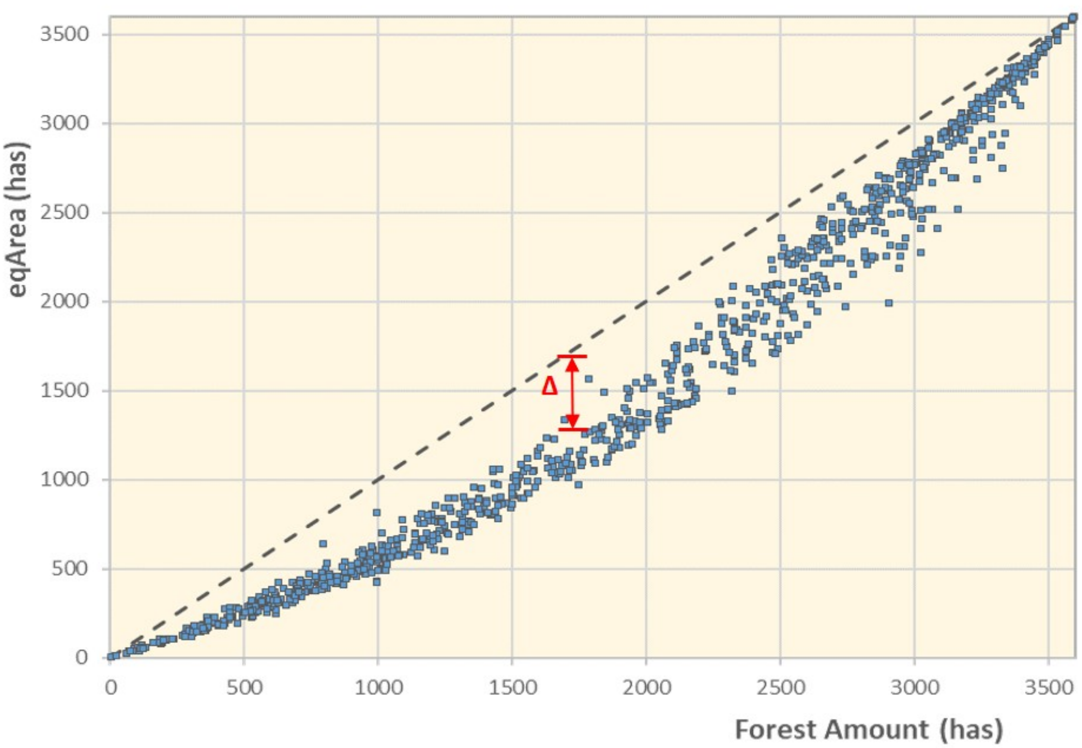
H: total habitat area,

S: Reachable landscape which is the habitat and its surrounding area, defined by a buffer of 500m.

And, ***Mean Quality*** as:

$$\bar{Q} = \frac{H_{eq}}{H}$$

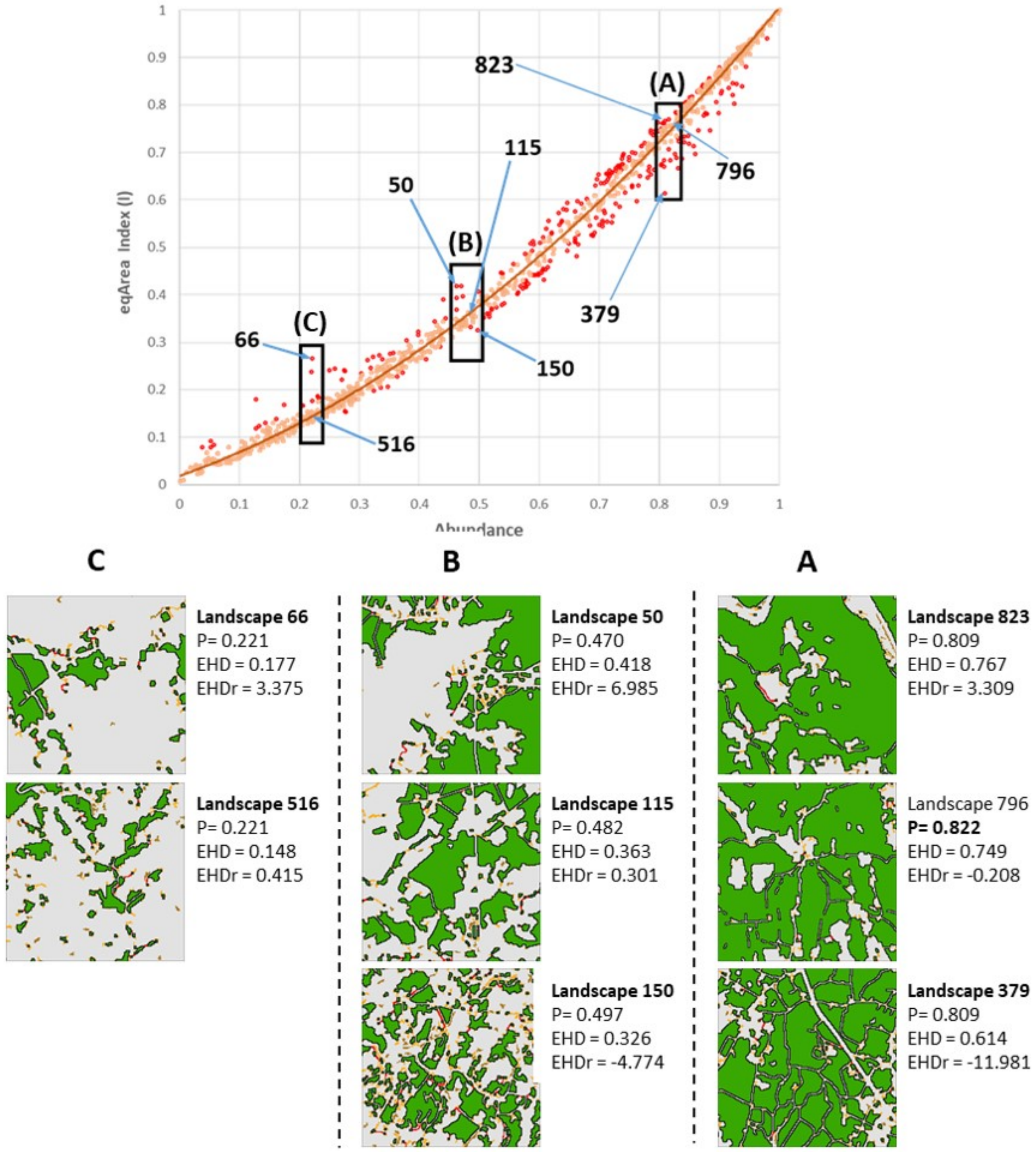
EHD is a class metric that also measures the proportion of habitat in the landscape, and therefore is strongly correlated with habitat abundance. However, unlike the original, this index depends on the structure and spatial organization of the habitat patches.



Relating EHD to habitat abundance, we observe effective habitat loss is most pronounced in landscapes with large amounts of habitat. It is notable that all landscapes fit almost perfectly to a curve across the entire abundance gradient in the basin. There are no sharp jumps nor different pathways, only a simple and very well-defined curve that we interpret as a global characteristic of the basin.

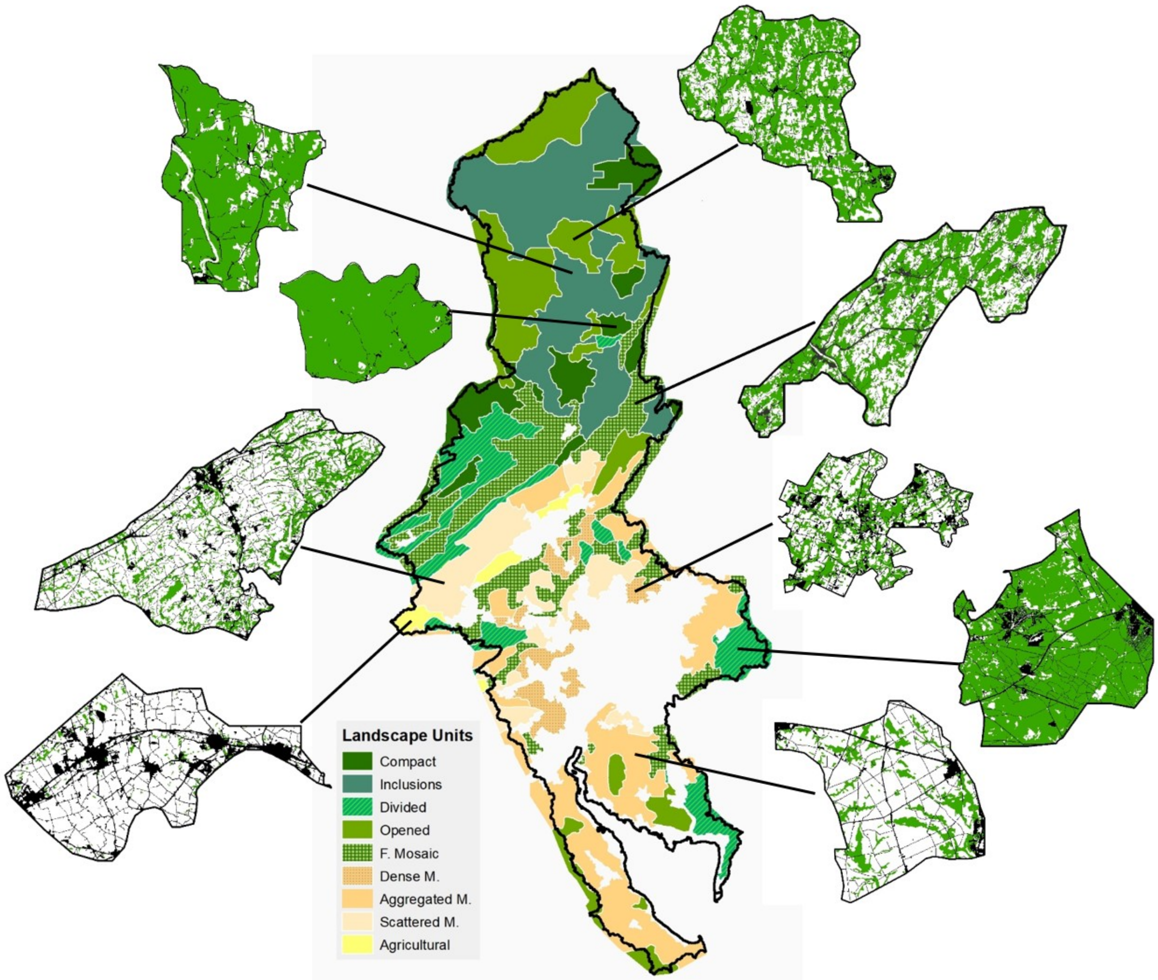
We define a new measure (EHDr), as the residual value between EHD of the landscape and a reference value defined by the best fit curve. EHDr is independent of habitat abundance and is an indicator of the degree of fragmentation in relation to landscapes with the same amount of habitat.

Habitat configuration is not easily comparable across landscapes with great differences in habitat abundance. So, residual indices relating metric values with a reference, like EHDr, become useful to discriminate more or less fragmented situations. EHDr is also more sensitive to a broader range of fragmetation cases than residual for traditional metrics alone.

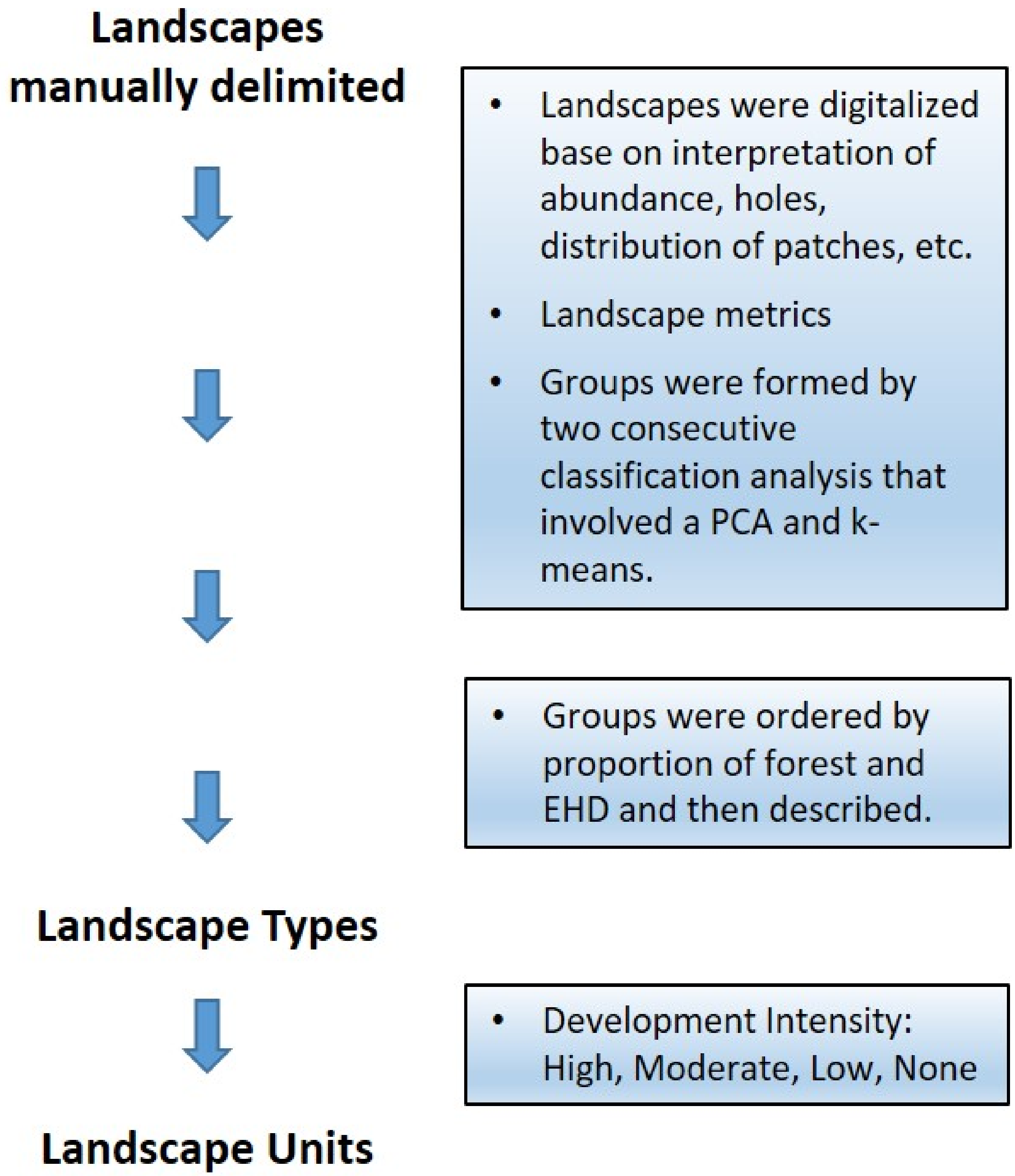


Spatial patterns of fragmentation vary depending on the landscape's habitat abundance. In densely forested landscapes, disection by roads is the principal factor of fragmentation while clumpiness, clustering and isolation are more important in defining the degree of fragmentation.

LANDSCAPES IN DRB



Nine landscape types were identified in DRB: four are forest dominated and three are mosaics of small forest patches in an agricultural and/or urban-suburban matrix. Between them there are two types making the transition from forested landscapes to mosaics. In this study we focus only on rural landscapes.

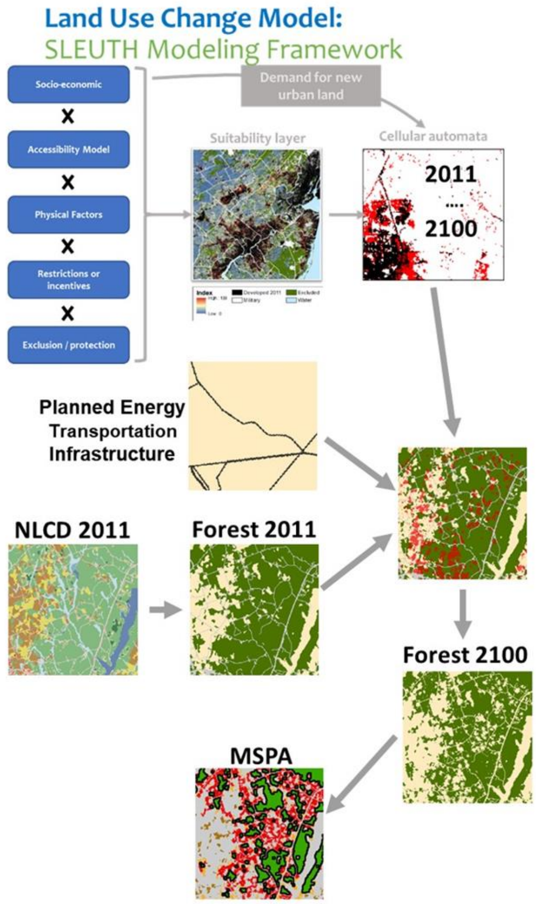


Landscape metrics in 2011

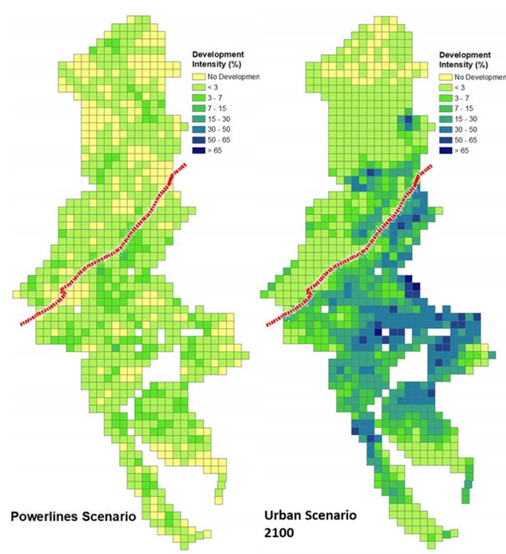
Landscape	ABUND	EHD	EHD.r	pd	ed	area	area.cv	core	core.cv	ndca	lpi	enn	enn.cv
Compact	0.96	0.94	-0.13	0.2	20.8	1106.5	310.4	1063.2	312.2	36.4	81.9	50.9	29.2
Forest with Inclusions	0.85	0.80	3.23	0.5	38.4	234.9	858.4	215.2	870.2	464.6	55.2	56.7	50.4
Divided	0.83	0.70	-3.71	1.3	55.5	82.4	282.3	72.2	296.6	419.9	20.2	50.2	37.9
Opened	0.69	0.58	3.43	1.1	54.6	74.8	531.9	63.0	553.9	738.5	22.4	63.4	64.9
Forest Mosaic	0.64	0.48	-1.14	2.3	73.6	28.9	254.4	22.4	279.9	569.6	7.7	58.0	57.1
Dense Mosaic	0.42	0.28	-1.15	3.7	76.9	11.7	214.2	7.6	256.6	680.3	2.5	66.2	74.7
Aggregated or Cleaned Mosaic	0.27	0.19	0.32	2.1	45.9	12.7	234.8	8.4	279.9	663.5	2.1	101.9	99.2
Scattered Mosaic	0.26	0.17	-1.23	3.1	57.0	8.5	178.5	5.0	225.2	724.8	1.5	90.6	86.0
Agricultural	0.03	0.03	0.00	0.8	8.8	3.2	143.6	1.3	218.1	129.0	0.3	322.6	111.8

Average landscape metrics for the 9 landscape types classified in DRB. The landscapes highlighted are pairs of types with similar habitat abundance but differences in spatial configuration.

URBAN MODEL AND PROJECTIONS



The land use change model takes a multi-factor approach where different drivers and conditions are combined to create a suitability map. The suitability map is introduced into the stochastic model (SLEUTH) to generate 100 simulations of urban growth up to year 2100. NLCD 2011 was used to obtain the current forest extent which is 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 urban 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).



Both scenarios are completely different with respect to the intensity of the perturbations and the distribution of the intensity. The urban growth is concentrated around current urban centers and especially at the eastern border of the basin. The last is related with growth process associated with the New York metropolitan area and highlights how circumstances occurring outside the basin can directly influence changes in the basin. On the other hand, the power lines scenario is much less intense and it is spread more evenly across the basin. In general, landscapes in the northern region are less transformed than the southern ones.

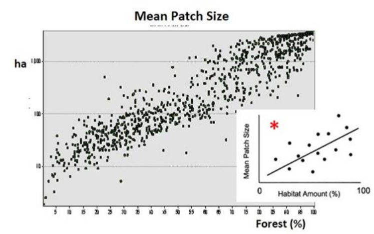
HABITAT FRAGMENTATION

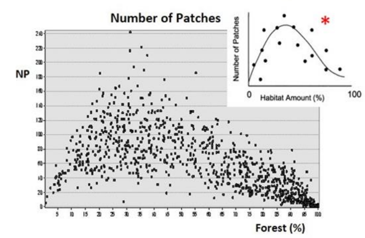
Landscape ecology focuses on understanding landscape heterogeneity and how it influences organisms, populations, and ecosystems (Turner and Gardner, 2015), and fragmentation has played a central role in this approach.

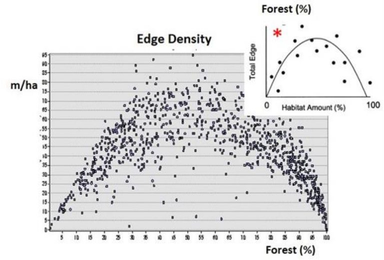
"Fragmentation is a process during which a large expanse of habitat is transformed into a number of smaller patches of smaller total area" (Wilcove, 1986)

Fragmentation is mainly driven by habitat loss where the reduction of habitat extent results in an increase of smaller and isolated habitat patches. These could have important implications on habitat quality relating to species viability and the organization and functioning of communities and natural ecosystems (Didham, et al, 2012).

But fragmentation is not only an issue related exclusively with habitat loss; it is also related with all effects derived from changes in the spatial arrangement of the habitat fragments. However, researchers have found it very difficult to differentiate habitat loss from fragmentation itself. Most of the metrics used to describe the spatial pattern of fragmentation have a strong correlation with habitat loss and our study area is not an exception.







Patch size, number of patches or edge density follow similar behavior along the abundance gradient as described by other authors.

* Figure obtained from Fahrig, Lenore. "Effects of Habitat Fragmentation on Biodiversity."

And to make things more complicated, the same amount of habitat loss can result in different spatial pattern change and opposite effects on the metrics.

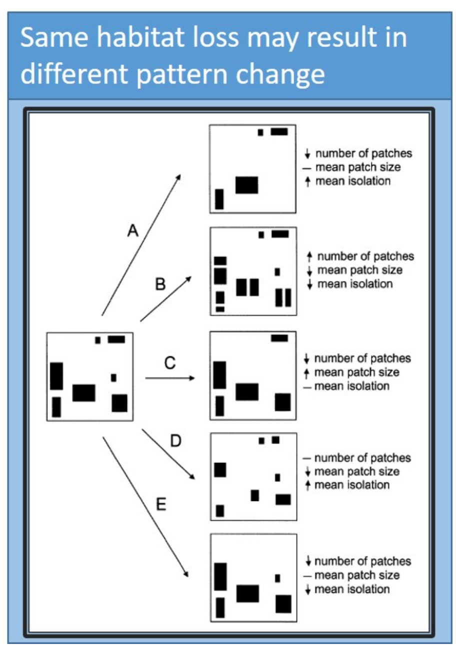
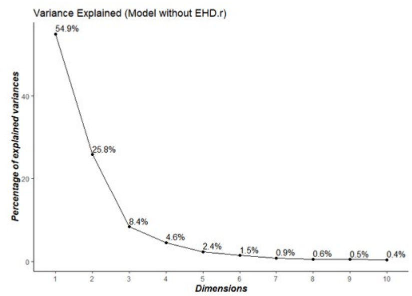


Figure obtained from Fahrig, Lenore. "Effects of Habitat Fragmentation on Biodiversity."

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 land cover change scenarios: one 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 assesses the impact of future energy infrastructure on forests by incorporating planned electricity transmission line construction.

RESULTS

Metric	Unit	Description
area	*ha*	Mean Patch Area (AREA_MN)
area.cv	*ha*	Patch Area Coefficient of Variation (AREA_CV)
core	*ha*	Mean of Core Area (CORE_MN)
division		Probability that two randomly selected cells are not located in the same patch (DIVISION)
ed	*m/100 ha*	Edge Density (ED)
enn	*m*	Mean of euclidean nearest-neighbor distance (ENN_MN)
enn.cv	*m*	Coefficient of variation of euclidean nearest-neighbor distance (ENN_CV)
lpi	*%*	Largest patch index (LPI)
ndca	*patches/ 100 ha*	Number of core patches (NDCA) in 100 ha of habitat.
pd	*patches/ 100 ha*	Patch Density (PD)
Mcore		Relative size of matrix patches. (=Mcore.mn/core.mn).
Mlpi	*%*	Largest patch index (LPI) of the matrix
Mndca	*patches/ 100 ha*	Number of matrix patches in 100 ha of landscape
EHD.r		EDH residual. Difference of EHD respect to the EHD expected considering the habitat abundance

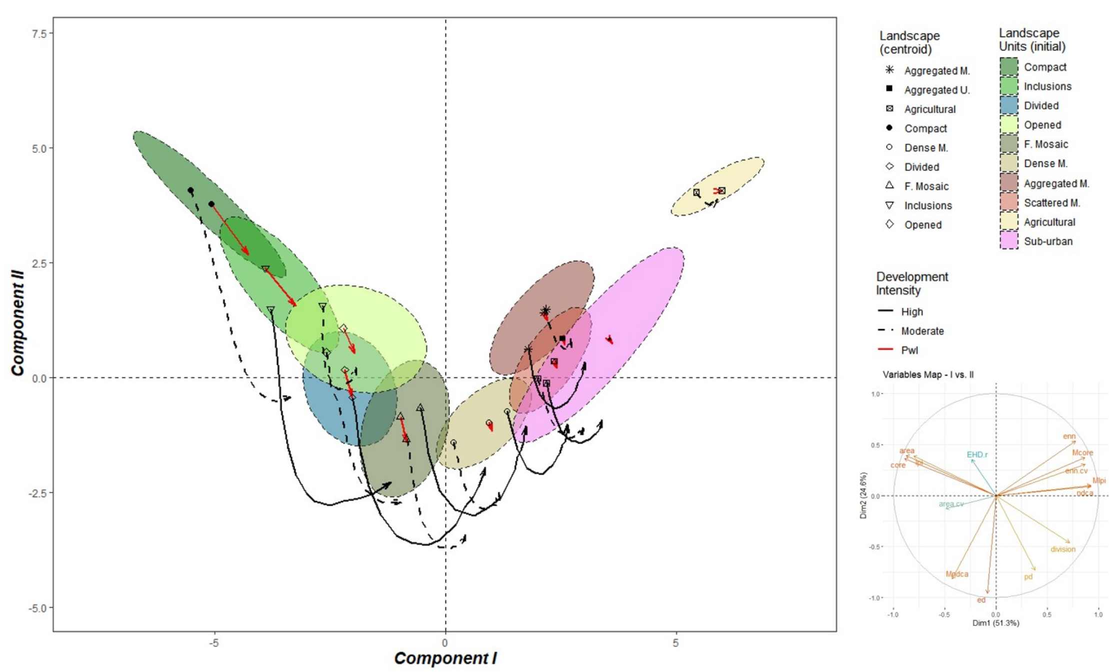


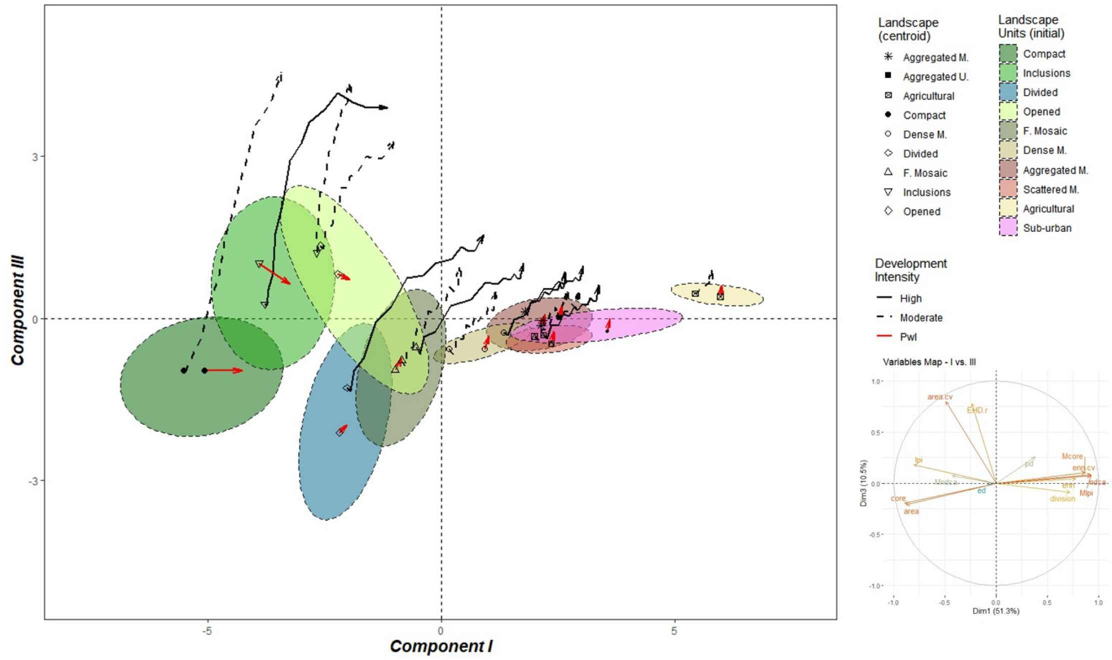
Components

	I	II	III	IV
+	***Matrix.lpi***		***area.cv***	***area.cv***
↑	***ndca***			
	enn.cv		*lpi*	*division*
	Mcore		*pd*	
		enn		
			division	*pd*
	area	*pd*		
↓	*core*	*Mndca*		
-		***ed***		

A set of landscape metrics were used to characterize and compare changes in spatial structure in response to urban development or power lines. The metrics selected are relevant in describing the number of habitat fragments, core areas and matrix, as well as their size, shape and isolation. Because we focused on analyzing changes in spatial structure, we did not include the analysis of metrics of habitat abundance. These metrics were calculated with the landscape metrics package for 13 habitat projections making a time series of 5 year intervals up to 2050 and 10 years intervals between 2050 to 2100.

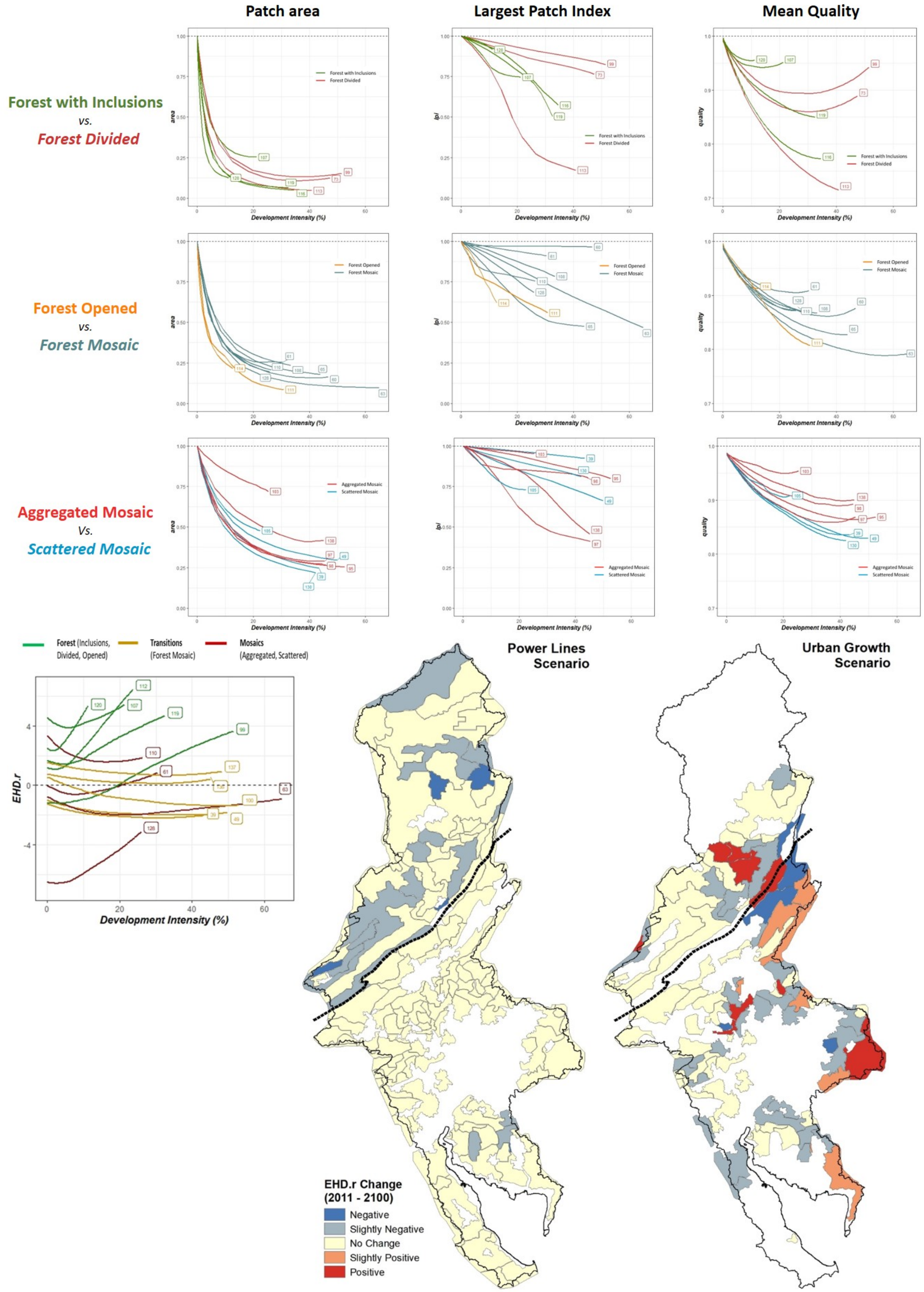
Principal components analysis was used to identify the main factors that explain the variation of spatial structure in the basin. PCA components were used to generate a space to characterize and compare changes in spatial structure in response to urban development or power lines. First and second components are related with the size of the habitat and matrix patches and the amount of edges and number of fragments. Altough habitat abundance metrics were not included in the analysis, component I is quite correlated with the amount of habitat. The first component related with EHDr is the third component.





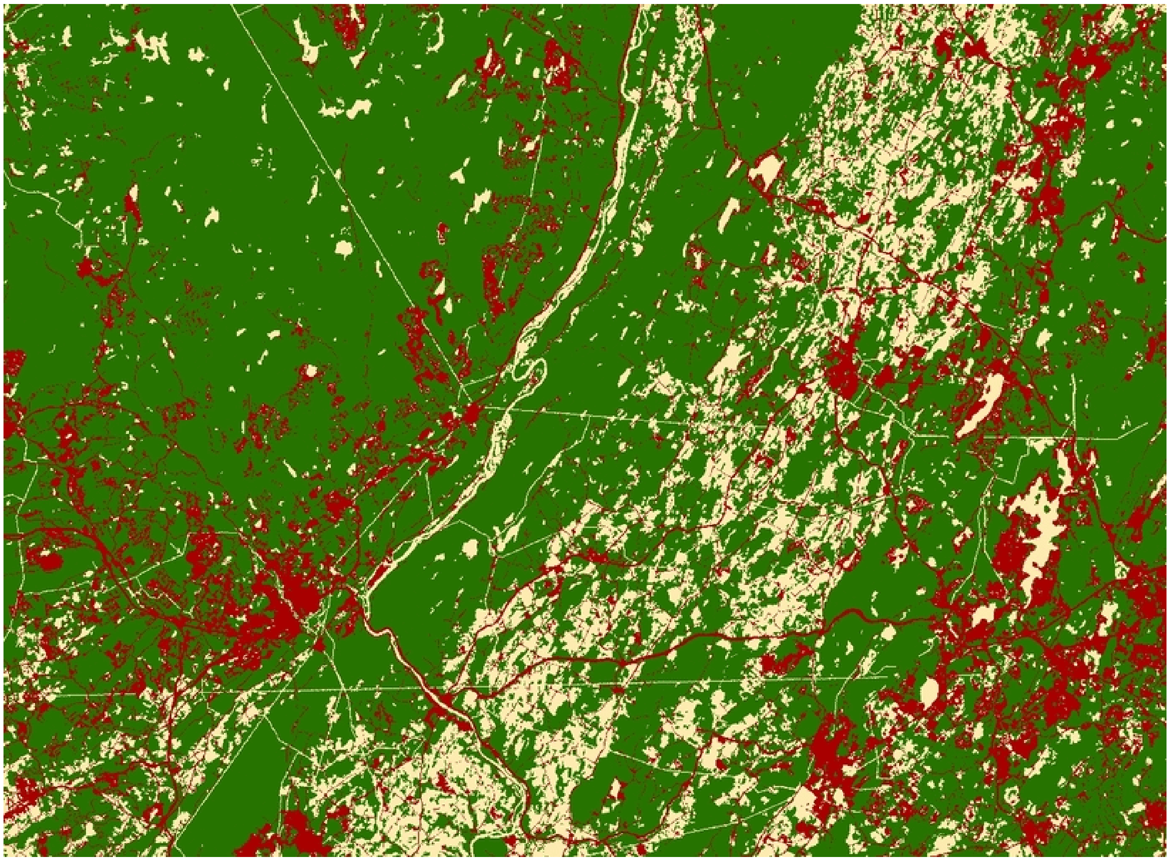
Principal component analysis bi-plots summarizing landscape metrics.Ellipses indicate the diitribution of 90% of the current landscape types (2011). The more habitats that are present, the more urban development and power lines patterns diverge and landscapes suffer bigger changes. If the current landscapes show the historical path of change (components I & II), urban development creates an alternative path with an initial increase of edge and fragments, and then removing fragments and simplifying shapes when initial developed nuclei start merging together. In landscapes dominated by forest, power lines trend to split patches while urban is more related to increased edge and small patches, but keeping large patches.

Comparison of evolution of some landscape metrics over development intensity gradients. Pairs are types with similar habitat abundance but different spatial characteristics and each line represents an example of a landscape unit. The behavior of indices apparently is dependent of the local conditions more than the initial structure or the amount of habitat.



The evolution of EHDr is not related with the spatial structure, however there is different behavior based on the initial amount of habitat. Indepently of the landscape, EHDr always shows a trend of an initial reduction followed by an increase values. This may be related to the spatial pattern of urban development. However, there are significant differences between landscapes, associated with the habitat amount, of when the inflection takes place and how much the index rises.

Power lines don't have a strong effect in most of the landscape units, but when they do it is toward a decrease in EHDr, making them more fragmented than expected. The lack of significant change is a consequence of the low density of new energy corridors in landscapes in the upper basin or because mosaics in the southern region absorb higher corridor densities.



Animated Example of one of the simulations. Green: forest; Red: Urban in 2011; Grey: Urban simulation.

CONCLUSIONS

- Linear patterns of land use change (e.g. transportation) may produce more fragmentation with less habitat loss than clumped patterns. The first results mainly in a process of division while the second one acts by increasing edge.
- Many factors can influence the urban growth fragmentation pattern: forest abundance, topography, or conservation areas, and there is not a single recipe.
- Initial conditions of habitat pattern may influence the process fragmentation. For example, aggregated patterns may prevent slight habitat loss, however the influence can be shaped by other circumstances.
- Principal divergences from the historical pattern arise when urbanization occurs in landscapes with a large amount of forest. This is relatively new and is expected to increase in the future when metropolitan suburbs reach forested landscapes.
- Although development in forested areas can be theoretically less fragmented than expected, the study did not include the transportation network associated with development, which would further increase fragmentation.
- We should consider the new matrix will be less suitable and perturbations will increase, and connectivity probably will be an issue in some areas, but this is a subject for a future approach.

AUTHOR INFORMATION

Alfonso Yáñez Morillo

Research Analyst, Cenfer for Land Use and Sustainability

A.S. in forest engineering from the Universidad Politecnica of Madrid
B.S. in biology from the Universidad Complutense of Madrid
M.S. in environmental management and administration from the Fundación Biodiversidad

Alfonso specializes in landscape ecology and connectivity and has over 10 years experience applying GIS to a wide range of environmental consultancy projects. Focus areas include environmental impact assessments, land use change, planning evaluation, forest fires, and ecological flows regimes.

Claire Jantz, Ph.D

Professor, Department of Geography-Earth Science

Director, Center for Land Use and Sustainability

B.A. in College Scholars from University of Tennessee
M.A. in Geography from University of Maryland
Ph.D. in Geography from University of Maryland

Dr. Claire Jantz is the Director of the CLUS. She has extensive expertise in land use and land cover change analysis and modeling, and interdisciplinary research. Dr. Jantz has particular expertise within the Chesapeake Bay Watershed, the Delaware River Basin, and the Delmarva Peninsula. She has participated in several collaborative research efforts funded by NASA, Maryland SeaGrant, NPS, and the William Penn Foundation.

ABSTRACT

Our objective is to analyze changes in forest cover and structure in the Delaware River Basin. Specifically, we (1) measure and locate expected forest loss and quantify the risk of loss in 2100 related to future urban development given “sprawl” and future energy infrastructure by incorporating planned electric transmission lines, (2) identify spatial configuration patterns and verify whether future patterns of change conform or contrast with existing ones, and (3) consider whether less fragmented landscapes are able to better absorb the effects of different forest loss patterns or are more susceptible to drastic changes than more fragmented landscapes.

Morphological Spatial Pattern Analysis (MPSA) was used to divide forest patches into structural classes (core area, edge, corridors, etc.) Synthetic metrics were then calculated by weighting the structural classes based on their ecological role. In our projections of future growth, there is a basin-wide increase in urbanized area and transmission lines of 4.5% to 8.5%, which represents a basin-wide loss of 1.83% to 4.19% of current forest area. The most dramatic changes occur along the eastern boundary of the basin due to the influence of New York City’s metropolitan area.

While expansion of urban and suburban areas in the rural landscape is already occurring in the river basin, our forecasts demonstrate new patterns when growth occurs in forested landscapes. Urban growth generates a more compact and aggregated pattern than that generated by agricultural activities. Although currently marginal, the new patterns are expected to increase in frequency as urban-forest contact areas increase, producing important ecological implications. This transformation is of the utmost importance, as it will affect well-conserved landscapes: since an increasingly urban landscape is more restrictive and limiting for ecological processes, it will impact habitat quality and connectivity.

REFERENCES

Clarke K.C., Gaydos L.J., 1998. Loose-coupling a cellular automaton model and GIS: long-term urban growth prediction for San Francisco and Washington/Baltimore. International Journal of Geographical Information Science 12, 699–714. https://doi.org/10.1080/136588198241617

Cushman S.A., McGarigal K. 2007 Multivariate Landscape Trajectory Analysis. In: Bissonette J.A., Storch I. (eds) Temporal Dimensions of Landscape Ecology. Springer, Boston, MA. https://doi.org/10.1007/978-0-387-45447-4_8

Didham R.K., Kapos V., Ewers R.M. 2012. Rethinking the conceptual foundations of habitat fragmentation research. Oikos 121, 161–170. https:// doi.org/10.1111/j.1600-0706.2011.20273.x

Fahrig, L. 2003. Effects of habitat fragmentation on biodiversity. Annual Review of Ecology, Evolution, and Systematics. 34: 487–515. doi:10.1146/annurev.ecolsys.34.011802.132419.

Harris C.D., Bissonette J.A., David J.L. 1998. The behavior of landscape metrics commonly used in the study of habitat fragmentation. Landscape Ecology 13: 167-186

James M.A.A., Fortin MJ., Fall A. Kneeshaw D., Messier C. 2007. The effects of Spatial Legacies following Shifting Management Practices and Fire on Boreal Forest Age Structure. Ecosystems 10: 1216-1277, DOI: 10.1007-007-9095-y

Kupfer J.A. 2012. Landscape ecology and biogeography: Rethinking landscape metrics in a post-FRAGSTATS landscape. Progress in Physical Geography: Earth and Environment 36, 400–420. https:// doi.org/10.1177/0309133312439594

McGarigal, K., Cushman S.A. 2012. FRAGSTATS v4: Spatial Pattern Analysis Program for Categorical and Continuous Maps. Computer software program produced by the authors at the University of Massachusetts, Amherst. Available at the following web site: http://www.umass.edu/ landeco/research/fragstats/fragstats.html

Turner M.G., Gardner R.H. 2015. Landscape Ecology in Theory and Practice: Pattern and Process, 2nd ed. Springer-Verlag, New York.

Vogt P. & Riitters K. 2017: GuidosToolbox: universal digital image object analysis. European Journal of Remote Sensing (TEJR), DOI: http:// dx.doi.org/10.1080/22797254.2017.1330650

Wang X., Blanchet F.G., Koper N. 2014. Measuring habitat fragmentation: An evaluation of landscape pattern metrics. Methods in Ecology and Evolution 5, 634–646. https://doi.org/10.1111/2041-210X.12198