

QUANTIFYING THE ECOLOGICAL PATTERNS OF URBAN DENSIFICATION THROUGH MULTIPLE ENDMEMBER SPECTRAL MIXTURE ANALYSIS, LANDSCAPE METRICS, AND FUZZY LOGIC

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ABSTRACT:

This paper introduces an integrative methodology that has been developed to measure temporal changes in urban morphology based on the techniques of multiple endmember spectral mixture analysis (MESMA), landscape metrics, and fuzzy logic. In order to illustrate an application of the methodology, the paper uses two satellite images acquired in 1990 and 2000 for the metropolitan area of Los Angeles County, California, a megacity with complex morphological patterns that are rapidly changing due to a range of complex, interrelated forces of urbanization that are poorly understood. Through a wall-to-wall exercise, the paper discusses: (1) how the spatially continuous character of urban morphology in Los Angeles has been analyzed through the MESMA technique to capture and quantify within-class changes at the sub-pixel level; (2) how the magnitudes of changes have been assessed through fuzzy logic; and (3) how landscape metrics have been applied to quantify the ecological patterns of change at the census tract level.

1. INTRODUCTION

1.1 Background

Satellite remote sensing has been widely recognized as one of the essential technological tools for sustainable development. A considerable number of recent studies has been conducted utilizing satellite sensor data in the analysis of urban change (e.g. Kwarteng and Chavez, 1998; Costa and Cintra, 1999; Chen et al., 2000; Ward et al., 2000; Batty and Howes, 2001; Madhavan et al., 2001; Yang and Lo, 2002; Herold et al., 2003; Weber and Puissant, 2003; Rashed et al., 2004). The findings of these studies have enriched our understanding of the physical and socioeconomic drivers of changes in urban land cover and the implications of these changes on land use practices and resource management in cities. Some of these studies went further beyond the characterization of change and its causes and attempted to integrate remotely sensed data with models of urban growth in order to project future changes in a given city. Looking back at how these studies have informed and been linked to sustainability policies, one can easily observe the sole focus on only one type of sustainable development, the so-called "smart growth," "managed growth," or "new urbanism." These and other similar approaches direct attention to changes that occur at the urban fringe, as in the case of "edge cities" in the U.S. and decentralized suburban communities in Europe.

However, few studies have directed attention to another important mode of urban land cover and land use change taking place within existing landscapes in cities (Rashed et al., 2004). Urban landscapes change over time as new urban fabric is added and also as the existing fabric is internally modified (e.g. new buildings replace old ones, plots are amalgamated or subdivided, street layouts are modified) (Knox, 1995; Cadwallader, 1996). These patterns of urban densification and internal modifications are of major concern to sustainable development because they represent the physical manifestation of a range of social, economic, cultural, and political dimensions associated with urban dynamics. Moreover, densification typically takes place locally within urban neighborhoods where the impact of sustainable policies is more spatially and socially manifested. Hence, a better characterization and quantification of densification patterns at the local level will both provide a rich understanding of the processes involved and challenge the credibility of policy, citizens' preferences for sustainable living space, and

developers' understanding of and attitude towards those preferences (Webster and Senior, 1999).

This paper introduces a methodology for quantifying the ecological patterns of urban densification taking place at the local or microscale level based on satellite imagery. The suggested methodology builds on a rigorous framework of urban landscape ecology (Ridd, 1995) and integrates the techniques of multiple endmember spectral mixture analysis (MESMA), landscape metrics, and fuzzy logic. The proposed methodology brings these techniques together in a way that allows for: (1) a better decomposition of the urban landscape into its underlying land cover materials; (2) an improved assessment of urban land cover change that takes into account not only changes between land cover classes but also within land cover classes, and quantifies the actual magnitude of this change (e.g. high increase, lower decrease, no change, etc); and (3) a quantitative comparison of the ecological patterns of change in land cover between urban locales. In the following sections, the proposed methodology is described and its application is demonstrated through a case study that utilized Landsat data to quantify urban land cover change in Los Angeles County, California, between 1990 and 2000.

2. METHODS

2.1 Approach

The proposed methodology for quantifying the ecological patterns of urban densification consists of three sequential phases. In the first phase, the MESMA technique is separately applied to individual images in order to derive per-pixel physical measures of urban land cover abundance at a given point of time. Land cover fractions of individual dates are then validated against test data to determine the accuracy of MESMA-derived measures. Once acceptable, multi-date fractions of corresponding land cover materials are used to calculate per-pixel temporal differences in these fractions. Hence, the resultant fractional differences will represent a direct measure of the changes that take place in the composition of urban morphological patterns over time due to such processes as urban densification and urban sprawl. In the second phase of the methodology, the magnitude of change in land cover fractions is estimated through fuzzy logic. A number of predefined fuzzy membership functions are applied to characterize the magnitude of change in each type of urban land

cover (i.e. higher increase, lower decrease, etc) according to a threshold that indicates a specific degree of certainty. In the third phase, the boundaries of local zones within a given urban region (e.g. urban blocks, census tracts, zip codes) are used to average the magnitudes of change in each land cover type from the pixels that fall within individual zones. Next, landscape metrics are applied to these zonal averages to quantify the ecological patterns of a given magnitude of change in a given land cover within a given local zone. The calculated metrics can then be used to compare urban local areas in terms of the ecological patterns of change associated with urban densification and other drivers of internal morphological change in urban areas. The following sections outline in more detail the methods used in the three phases described above.

2.2 MESMA

Spectral mixture analysis (SMA) (Adams et al., 1993) is one of the techniques proposed to provide a solution to the problem of mixed pixels in urban satellite imagery with medium spatial resolution (i.e. 20m or lower). Findings from recent studies indicate that although SMA provides superior results to traditional per-pixel classification techniques when applied to urban imagery, a considerable degree of error may be associated with SMA models (Ward et al., 2000; Rashed et al., 2001; Small, 2001). This is because the standard SMA model implements an invariable set of endmembers to model the spectra in all the pixels within an image. This assumption fails to account for the fact that, due to the diversity of urban materials, the number and type of components within the satellite sensor's field of view are variable. Roberts et al. (1998) proposed a solution to this problem by developing a modified SMA algorithm that allows the number and type of endmembers to vary for each pixel in an image. This technique is referred to as multiple endmember spectral mixture analysis or MEMSA. Thus, MESMA can be described as a modified linear SMA approach in which many simple SMA models are first calculated for each pixel in the image. The objective is then to choose, for every pixel in the image, which model amongst the candidate models provides the best fit to the pixel spectrum while producing physically reasonable fractions (Roberts et al., 1998; Rashed et al., 2003).

The procedure of applying MESMA to urban satellite imagery is described in detail in Rashed et al (2003). However, it is worthwhile to highlight here some important aspects of this procedure to provide a context for the case study described in this paper. Applying MESMA to a single-date image starts by selecting a set of candidate endmembers believed to represent a relatively pure spectral response of the target materials in the scene. A conceptual framework for urban landscape ecology devised by Ridd (1995) becomes very useful in this regard. Ridd suggested that urban areas may be described in terms of proportions of Vegetation (V), Impervious surfaces (I), and Soil (S). The process of endmember selection is commenced by applying the Pixel Purity Index (PPI) method, developed by Boardman *et al.* (1995), to screen all the pixels in the image in terms of their relative purity. In the next step, a series of standard SMA models are applied based on a variety of possible combinations of the selected endmembers. The performance of all models is evaluated so that a smallest subset of candidate models can be selected for every pixel in the image. A reliable candidate model is one that produces physically realistic fractions (i.e. 0-100% range) and does not exceed a certain threshold of error. From the selected candidate models, an optimal model is then identified for each pixel based on the classical maximal covering problem, originally introduced by

Church and ReVelle (1974). Finally, the fraction values produced by these optimal models are utilized to map the abundance of general land cover components in the urban scene at a given point of time.

The final results from applying MESMA to each single-date image are validated using aerial photos, following a process described in Peddle *et al.* (1999). In this process, a stratified adaptive cluster sampling (SACS) method is used to identify a number of test sites on the aerial photos. The accumulation of corresponding endmember fractions is calculated to estimate the area of a test site based on the land cover fractions modeled by MESMA. The accuracy of each endmember fraction is estimated as the mean of the absolute difference (%) between actual and modeled cover estimates derived from aerial photos and MESMA, respectively.

2.3 Change Analysis through Fuzzy Logic

Fuzzy methods in remote sensing have received growing interest in recent years (Foody, 1999; Foody, 2001). This paper presents a methodology in which fuzzy models operate in a subservient role to MESMA models. The application of fuzzy logic to quantifying magnitudes of urban land cover change is highly appealing because of its capability to deal with uncertainties such as in the case when one cannot accurately identify a threshold value to separate areas of change from areas of no-change. Fuzzy logic is a superset of Boolean logic that has been extended to handle the concept of partial truth values between "certainly true" and "certainly false." Fuzzy sets are sets without sharp boundaries in which the transition between membership and non-membership is gradual (Zadeh, 1975). This gradient corresponds to the degree to which an element (e.g. a pixel) is compatible with the concept represented by a fuzzy set. Thus, elements may belong to the fuzzy set to a greater or lesser degree as indicated by a larger or smaller membership grade.

Once MESMA fractions are calculated for each individual date, change can be identified in a straightforward way by subtracting each class of land cover fractions at Date 1 from their corresponding fractions at Date 2. The resultant fractional differences represent the temporal change in land cover abundance in each pixel in absolute terms. To assess the magnitude of this temporal change, the proposed methodology applies fuzzy sets representing varying degrees of change (high increase, lower decrease, etc). This "fuzzification" of change involves two steps. The first is to translate the concept of magnitude of change into fuzzy sets using sigmoidal (or S-curve) membership functions, which are very effective in modeling continuous, nonlinear phenomena (Cox, 1999). The case study described in this paper utilizes five fuzzy sets representing the following levels of change: higher increase, lower increase, no change, lower decrease, and higher decrease. The equations used to generate these functions are listed and discussed in Rashed et al. (2004). The second step of the fuzzification process is to apply these fuzzy sets to the 'change-in-fraction images,' which represent change in endmember fractions. This step results in new images representing the five magnitudes of change in each land cover class on a pixel-by-pixel basis.

2.4 Landscape Metrics

Landscape metrics are indices developed for categorical map patterns. Their development has been based on both information theory and fractal geometry (Herold et al., 2002). Categorical map patterns represent data in which the ecosystem property of interest is represented as a mosaic of patches. Patches represent

discrete areas of relatively homogeneous environmental conditions, the definition of which is artificially imposed according to a phenomenon of interest and only meaningful when referenced to a particular scale. For example, the urban landscape of Los Angeles can be described as a mosaic of census tracts. The census tract in this case can be thought of as a patch that is relatively homogeneous in terms of social and physical characteristics. Similarly, at a larger scale, a census tract can be viewed as a mosaic (or landscape) of its own, consisting of smaller patches of land cover classes represented by a collection of pixels in a remotely sensed image. While individual pixels (the construction blocks of patches) possess uniform spatial characteristics (e.g., identical size, perimeter, and shape), the aggregation of these pixels provides a rich set of properties. These properties depend on whether the pixels are aggregated over a single land cover class (patch) or multiple classes, and whether the aggregation is considered within a specified census tract. Landscape metrics make use of these properties to reveal the spatial character and distribution of patches, and thus to quantify landscape patterns (O'Neill et al., 1988).

The proposed methodology uses a subset of landscape metrics as a way of quantifying the configuration and composition of spatial variation of land cover fraction changes produced by MESMA. Calculating these metrics at the census tract level (i.e., each tract is considered as a collection of land cover patches) provides an additional means of establishing and testing the link between both social and physical drivers of urban land cover change and sustainable policies implemented at the local level. The temporal differences in land cover fractions produced by MESMA are typically represented in terms of the change of the areal percentage occupied by a fractional class of land cover within a pixel. However, landscape metrics operate on the assumption that individual patches are homogeneous at the patch level. Therefore, before landscape metrics can be applied, fractional differences have to be reclassified such that each pixel within any census tract corresponds to one, and only one, magnitude of land cover change (i.e. higher increase, lower decrease, etc). To do so, each individual pixel in the fuzzified layers of change produced in the previous phase is screened in terms of whether or not it meets a threshold of the degree of membership (e.g. 0.7 in the case study presented herein) in a certain magnitude of change. If a pixel value (i.e. the degree of membership in a specific magnitude class) is equal to or greater than this threshold, the pixel is classified under this magnitude of change. Thus, there may exist up to five classes of change magnitude (higher increase, lower increase, no change, lower decrease, and higher decrease) calculated for each class within any census tract.

The next step is to select a subset of landscape metrics that best quantifies the ecological patterns of land cover change within the census tracts in a given study area. The ecological patterns are quantified in terms of the configuration of patches of pixels of a given magnitude of change in a given land cover class within a census tract (i.e. class level metrics). Table 1 shows the subsets of metrics that have been used in the case study presented in this paper. As shown in the table, there are metrics that essentially measure different properties in the same way and at the same level such as PLADJ and AI. Thus, we should expect that some of the measures resulting from these metrics would be highly correlated with each other. This redundancy is deemed important in the proposed methodology because each metric points to a slightly different aspect of the spatial structure of urban places. In the case study presented below, the calculation of all these metrics was done through a software

package called FRAGSTATS (version 3), designed to compute a wide variety of landscape metrics for categorical map patterns.

Table 1: Description of landscape metrics applied at the land cover class level within a census tract

Class Metrics	
Metric	Property Measured
PD - Patch density	Areal composition
LPI - Largest patch index	Areal composition
PAFRAC - Perimeter-Area Fractal Dimension	Shape complexity
PLADJ - Percentage of Like Adjacencies	Degree of aggregation of land cover class
AI - Index of Aggregation	Degree of aggregation of land cover class
IJI - Interspersion and Juxtaposition Index	Degree of interspersion or intermixing of land cover class
DIVISION	Diversity of land cover class
COHESION	Physical connectedness of the land cover class

3. TESTING THE METHODOLOGY IN LOS ANGELES

3.1 Study Area and Data

The study area used to test the proposed methodology is Los Angeles County, California, a dynamic and data-rich region that has undergone dramatic changes towards sustainable policies. In the 1980s, urban planners and policy makers began to formulate broader policies for sustainability (e.g. the 1989 Air Quality Management Plan) and implement tangible processes of technological and procedural change designed to allow cities in this region to use less energy and materials, to pollute less, and to create more durable social relationships with nature (Keil and Desfor, 2003). Nurtured by the region's strong growth control movement in residential neighborhoods, Los Angeles' planning and policies in the late 1990s began to reflect a leaning towards vertical growth and urban greenness (Pincetl et al., 2003). Projects have been conducted to transform small interstitial spaces into greened open spaces, particularly in parts of the region that were rated park poor. Although it is too early for one to assess the degree to which these sustainable policies and efforts have been successful in such a complex and diverse region as Los Angeles County, there are indicators that can be used to assess the progress. In the present case study, the proposed methodology has been used to extract physical indicators associated with neighborhood densification in the regions to quantify the ecological patterns of change associated with this process.

The data utilized in the application of proposed methodology included subsets (3113 lines X 4801 samples) from two Landsat TM and ETM+ images acquired in September 1990 and July 2000 respectively (path 41, row 36). Both images have 0% cloud cover. In addition to the multispectral images, the case study utilized a set of 1.0 m spatial resolution aerial photos to aid in the validation of the resultant endmember fractions. These photos represented a 1:12 000 color reproduction of high resolution visible color aerial photography acquired in late 1993 by I. K. Curtis Services, Inc., from an altitude of 2743.2 m using an RC10 aerial survey camera.

3.2 Results from Applying MESMA

Two individual subsets of image endmembers were selected independently for two dates, one for each image. These subsets were chosen according to a modified VIS model: vegetation (V), impervious surface (I), bare soil (S), and, the modification, water or shade. The latter endmember type, shade, was used here as a proxy for building heights based on the assumption

that, since the two images acquired from sensors with the same orbital properties, a change of building heights between the two dates will be reflected in a change of shade fractions. Likewise, dense development of urban neighborhoods and addition of trees should be reflected in an increase in shade fractions, while deforestation and removal of trees should be reflected in a decrease in shade fractions. The final two sets of endmembers selected in the image were linked to their respective image to determine their physical correspondence in the urban scene and included the following endmembers (for each date):

1. One endmember for the water (the ocean, lakes) and shade category (**shd**).
2. Two endmembers for the green vegetation category (**veg1 & veg2**). Veg1 corresponded to urban vegetation found in residential lawns, gardens, parks, golf courses, cemeteries, and shrublands, while Veg2 was used for natural vegetation located in the coastal sage and chaparral occupying the lower elevations of the Santa Monica and San Gabriel mountains, in addition to the oak-grass woodland located in the eastern portion of the image. A slight difference was observed between the spectral profiles of these two vegetation endmembers due to the level of water content, which is higher in natural green vegetation than in urban vegetation.
3. Two endmembers for the impervious surface category (**imp1 & imp2**). The first was used as an endmember for parking lots and dark gray roads, while the second corresponded to red tile roofs and wood shingle roofs.
4. Two endmembers for the soil category (**soil1 & soil2**). The first corresponded to bare soil in the urban scene, while the latter corresponded to sparsely vegetated soils. Observed differences in the spectral profiles of these two endmembers result from variations in the organic matter and mineral compositions.

Figure 1 shows the multi-temporal endmember fractions of vegetation, impervious surface, soil and water/shade for the northwestern (NW) portion of Los Angeles near San Fernando Valley. The fractions were produced independently from applying MESMA to the two multispectral images. Brighter areas indicate a higher fractional abundance, while darker areas indicate lower abundance. The fractions provide a measure of the physical properties of the dominant land cover classes in the scene at two different dates, thus helping to reveal the morphological patterns of neighborhoods in this part of Los Angeles at two different snapshots in time. Obvious changes between 1990 and 2000 are readily observed in Figure 1 with respect to an increase in the brightness of vegetation and shade fractions, and a decrease in the brightness of soil and impervious surface fractions. Nevertheless, the spatial patterns of the fractional abundance of all land cover classes in the two dates are very similar. A similar interpretation can be drawn for all of Los Angeles County (not shown). This suggests that patterns of morphological change in Los Angeles are primarily within land cover classes rather than between land cover classes. In other words, change in land cover is still taking place at the sub-pixel level but not so much at the pixel level. Thus, a crisp classification would likely result in a misleading conclusion that no change is taking place in Los Angeles. MESMA, however, shows that urban morphology in Los Angeles is actually undergoing continuous changes.

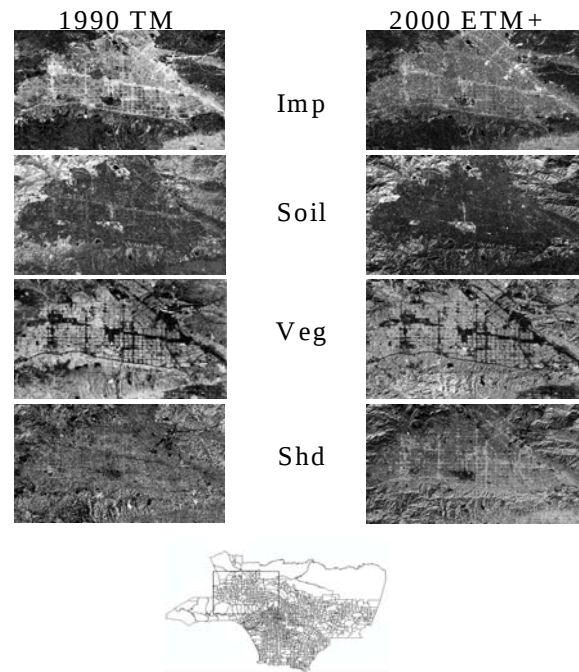


Figure 1: MESMA Land Cover Fractions for the NW portion of Los Angeles

The accuracy of MESMA fractions was assessed by comparing the accumulated fraction estimates in areas with relatively homogeneous land cover that did not experience change in fractions between the two dates with areal estimates derived from the higher resolution aerial photos (Table 1)

Table2: Results of the Accuracy Assessment of MESMA Fractions. Calculation method can be found in Peddle et al (1999) and Rashed et al. (2003). Areas measures in M2.

	1990			2000	
	Area of Reference Data	Area Estimated From accumulated fraction	Average Difference	Area Estimated From accumulated fraction	Average Difference
Vegetation					
Site1	242,500	235,889	0.052	238,624	0.051
Site2	211,250	222,629		234,688	
Site3	325,000	310,365		322,179	
Site4	1,034,375	1,120,759		1,117,548	
Impervious Surface					
Site1	101,875	103,411	0.088	101,934	0.063
Site2	1,743,125	1,829,180		1,815,604	
Site3	25,000	28,539		27,037	
Site4	718,750	822,654		835,140	
Soil					
Site1	128,125	137,078	0.046	142,694	0.054
Site2	125,000	132,115		136,527	
Site3	302,500	312,708		308,142	
Site4	1,321,250	1,288,430		1,315,549	
Shade					
Site1	310,625	258,210	0.100	326,800	0.077
Site2	298,125	325,682		314,758	
Site3	279,375	268,226		296,121	
Site4	450,000	495,366		514,364	

This approach was deemed sufficient because the 1993 aerial photos were acquired between the image acquisition dates (1990 & 2000). In addition, for most applications, one is interested in the aggregation of fraction measures over well-defined regions (e.g., census tracts, ecological fields) rather than individual pixels. The results shown in Table 2 indicate that there is good agreement between MESMA measures at both dates and the aerial photo-derived estimates for all four land cover classes. Both the vegetation and soil fractions have

the smallest total mean difference from the reference data aggregated over the test sites. The accuracy of the impervious surface fractions is slightly lower in Date1, while the shade fractions have the lowest accuracy in both dates. The overall accuracy results are also consistent with the individual results by site.

3.3 Results from Analyzing Change through Fuzzy Logic

Change measures were produced by subtracting the 1990 endmember fraction images from those of 2000. The advantage of using the fraction images produced by MESMA lies in their ability to reveal whether or not a change occurs, the direction of change (increase, decrease), as well as classes of land cover undergoing change. In order to improve interpretation of results, it was appropriate to analyze change at the census tract level rather than on a pixel-by-pixel basis. This is because census tracts represent a reasonable spatial unit in Los Angeles that accounts for the variations in demographic and socioeconomic variables. Furthermore, analyzing change at the census tract level helps establish a direct link between change in urban land cover and underlying population forces, thus offering an effective way for improving our understanding of the impact of sustainable policies. Once, the average amount of change per census tract was calculated from each image, fuzzy set functions indicating the different magnitudes of change in fraction (i.e. higher increase, lower increase, no change, lower decrease, and higher decrease) were then applied to indicate the degree of membership of each census tract in these sets. The end product was an index of the severity level of change for each land cover class assigned to each census tract. Based on these indices, a threshold should value was used to classify the census tracts according to the different levels of change severity. This threshold value indicated the degree to which one is certain about the compatibility of the final classification results with the change concepts represented by the fuzzy sets. The results presented in Figure 2 are based on a threshold value of 0.70.

As shown in the figure, the types of change in urban land cover vary remarkably between the core of the city and its periphery. In addition, the magnitudes of change in different types of land cover are generally limited to one of three levels: lower decrease, no-change, or lower increase. An exception to this are the shade fractions that do not encounter any decrease and have higher increases in both the center and southern parts of the region. The observed patterns of change in vegetation and soil fractions represent the typical trend one can find in megacities, where rapid urban growth tends to occur first, followed by slower internal modification in the old fabric of the city. In the case of vegetation, the magnitudes of change tend to be low and usually represent a decrease or loss of vegetation on the city edges. As one would expect, this trend is coupled with a contrasting pattern of change severity in impervious surface, which experiences lower increases on the periphery of the city. The effects of greenness policies in the southwestern region of Los Angeles (Keil and Desfor, 2003; Pincetl et al., 2003) reveal physical changes in vegetation cover and are reflected by an increase in vegetation fractions. At the same time, lower decreases can be observed in the impervious surface of the city. One explanation of this pattern is directly related to the relatively low spatial resolution of the multispectral images utilized in the analysis, compared to the varying character of Los Angeles' urban morphology. That is, change in impervious surface is observed where the morphological pattern of the urban area is relatively sparse. Change in impervious surface is difficult to observe where the pattern of the urban morphology

is dense. This is the case for downtown Los Angeles. This idea is augmented by the higher increases in shade fractions around the downtown, which can likely be attributed to the densification processes taking place in these highly populated areas.

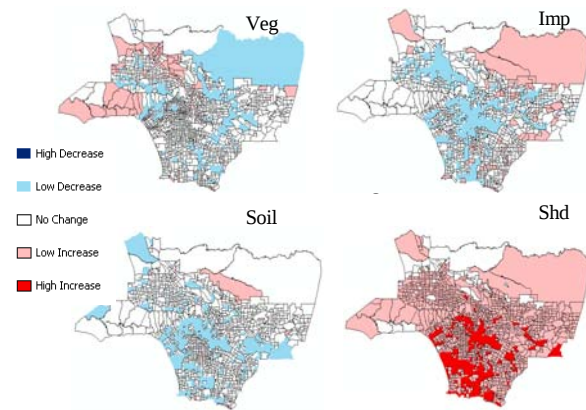


Figure 2: Census tracts in The Metropolitan Area of Los Angeles County Classified by the Magnitude of Changes in Land Cover Fractions

3.4 Results from Applying Landscape Metrics

Landscape metrics were applied to change fractions to quantify the ecological patterns (that is, the configuration) of land cover change at different magnitudes. These patterns describe the spatial character and arrangement, position, or orientation of pixel encountering a change in land cover within the urban locale. A full explanation of the results from this exercise is beyond the scope of this paper. However, to illustrate the usefulness of the proposed methodology, a sample of the results from applying landscape metrics is shown in Figure 3. Figure 3-A and 3-B respectively represent the degree of cohesion among pixels encountering increases and decreases within census tracts. The darker areas represent census tracts assigned to higher values in the cohesion index, whereas lighter areas represent lower values. Cohesion generally refers to the functional connections among patches within a landscape. In this example of vegetation change, functional connection may imply organized activities aiming to increase the greenness of urban areas (increase) or unsustainable practices (decrease) activities. As shown in Figure 3-A, census tracts near downtown and NW Los Angeles show a cluster of higher connectivity among pixels that experience vegetation increase (no matter what their magnitude is), which could be a reflection of efforts aiming at naturalizing the region. On the other hand, Figure 3-B shows a random pattern of pixels that experience vegetation decrease, which cannot be linked to organized activities that result in environmental degradation.

Comparing the patterns resulting from these two metrics with patterns of change in the impervious surface and soil fractions produced by either the same metrics or others, one can start comprehending the degree to which sustainable policies have become effective in Los Angeles County. Moreover, the fact that these metrics are assessed and calculated at the census tract level implies that one would be able to link these results to a range of demographic, socioeconomic and policy variables and thus to construct a full story of to what is going on in Los Angeles County, a story in which change is the rule not only in the periphery, but also in the core areas.

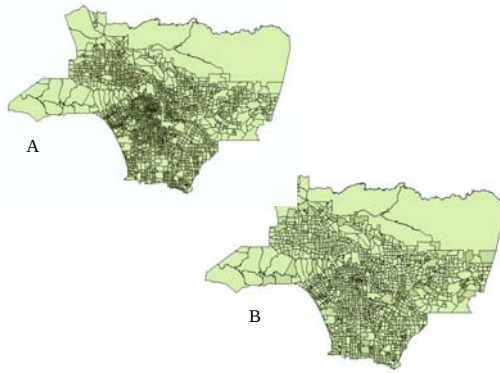


Figure 3: Calculated Cohesion Index for (A) Increase in Vegetation, (B) Decrease in Vegetation

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