# MODELING URBAN PATTERNS AND LANDSCAPE CHANGE IN CENTRAL PUGET SOUND

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**ABSTRACT:**
Patterns of urban development across the United States are changing natural landscapes and their dynamics. Although scholars in landscape ecology are increasingly studying the relationship between urban development and ecological conditions, few have directly addressed the question of how patterns of urban development affect landscape dynamics. In this paper we first propose that landscape patterns emerge from the spatial interactions between biophysical and socioeconomic processes. We then analyze urban patterns using landscape metrics to characterize their composition and configuration. We propose that distinct landscape signatures relevant to various ecosystem processes can be identified for different urban development patterns. Using selected landscape metrics we describe patterns of landscape change in the Central Puget Sound region between 1991 and 1999. The findings indicate two simultaneous key trends: the loss of forested land and the intensification of urban areas. Land conversion and increase in population density have been accompanied by an increase in dispersion of urban development and forest fragmentation. Identified trends have significant consequences for the response that ecosystems have shown to these human landscape alterations.

## INTRODUCTION

As complex dynamic systems, urban landscapes emerge from the local interactions of socio-economic and biophysical processes (Alberti 1999, and Alberti et al. 2003). These complex systems are highly heterogeneous, spatially nested, and hierarchically structured (Wu and David 2002, Portugali 2000, Gunderson and Holling 2002). Patterns in urban landscapes result from numerous locally made decisions involving multiple human and biophysical agents interacting among themselves and with their environment. Interactions within this complex domain between agents and processes are scale dependent.

Although several urban growth models have started to address the dynamics of human agents interacting with their environment (Landis and Zang 1998, Wilson 1998, Parker et al. 2003) they do not explicitly represent the interactions between human and biophysical processes that generate urban landscape patterns (McDonnel and Pickett 1990, McDonnel et al 1997, Grimm et al 2000, Pickett et al 2001, Alberti et al. 2003), nor do they represent the feedbacks from these interactions. Landscape ecology models, on the other hand, simulate land transformation over time as a result of biophysical processes but are limited in linking urban patterns with ecological effects since human agents and processes are not explicitly represented (Alberti 1999). While important progress has been made in modeling urban regions few models directly address the question of how human and ecological patterns emerge from the interactions between socio-economic and biophysical processes (Turner et a. 2005).

In this paper we first propose that landscape patterns are influenced by the interactions between biophysical and socioeconomic processes. We then propose that distinct landscape signatures relevant to various ecosystem processes can be identified for different urban development patterns. Using selected landscape metrics, we then describe patterns of landscape change in the Central Puget Sound region between 1991 and 1999.

## METHODS

The paper is developed around three major steps. First we apply a land cover change model (Alberti and Hepinstall, forthcoming) to show that landscape change, both its composition and configuration, is influenced by both socio-economic and biophysical variables. Second, we hypothesize that land development types can be discriminated using selected landscape features. We develop this analysis at two scales using both Landsat TM data (30m pixel) and digital orthophotos (1m pixel). Using discriminant function analysis (DFA), we assess the ability of impervious surface to discriminate between these different types of development. We then use selected landscape metrics to explore landscape trends in the eight-year period in Central Puget Sound and compare them to population growth within and outside the Urban Growth Area (UGA) established by the WA State Growth Management Act (GMA).

**Modeling Urban Landscape Patterns**

As part of a NSF Biocomplexity Project, Alberti and Hepinstall (forthcoming) develop a land cover change model for the Central Puget Sound (Figure 1) as a set of spatially explicit multinomial logit models of site-based land cover transitions. The probability of the transition of any land cover 30-m cell is a function of the interaction between the current land cover of the cell, its spatial context, and the spatial contagion of development. The model incorporates the spatial context of the 30-m cell by assigning to the cell the landscape composition and configuration of a 150-m window centered around the 30-m cell and determining the distance of the cell from recent and predicted development transitions.

Results from the implementation of the model in King County show that both land use and land cover patterns influence land cover change and are affected by them (Alberti and Hepinstall, forthcoming). The transition probability equations are estimated empirically as a function of a set of independent variables comparing land cover data for 1991 and 1999. We use Monte Carlo simulation to determine whether each pixel of a specified land cover changes to another cover type or remains in its current state. Land cover change equations are used to estimate the transition probabilities for each cell and the changes implemented by comparing the probabilities to a random number chosen from a uniform distribution between 0 and 1. The result of this procedure is the simulation of land cover change events that represent observed transitions between land cover classes.

**Landscape Signatures**

Ecological signatures of alternative development patterns in the Puget Sound metropolitan region can be quantified using land use and land cover pattern metrics. Researchers in landscape ecology have developed several metrics for quantifying such patterns (Turner et al. 1989, Turner et al. 2001). We develop two levels of analysis. Using Landsat TM (30m) data we estimated six metrics to measure urban landscape patterns within a 150 meter window: percent land (PLAND), mean patch size (MPS), contagion (C), Shannon index (SI), aggregation index (AI) and percent like adjacencies (PLADJ) Alberti et al. forthcoming). Land use data at the parcel level were obtained for King and Snohomish County assessor office. Land cover data were interpreted from Landsat Thematic Mapper (TM) imagery for the Puget Sound region for 1991 and 1999. The percent of land cover occupied by each patch type (i.e. paved land, forest, or grass) is considered an important indicator of ecological conditions since some ecological properties of a patch can be influenced by the composition of the patches and abundance of similar patches within the landscape. Percent Land is the sum of the area of all patches of the corresponding patch type divided by total landscape area. Mean Patch Size is the sum of the areas of all patches divided by the number of patches. Contagion is the probability that two randomly chosen adjacent cells belong to the same class. The Shannon diversity index represents the number of land use classes in the landscape.

We quantify landscape configuration also using aggregation AI and PLADJ indices. AI equals the number of like adjacencies involving the corresponding class, divided by the maximum possible number of like adjacencies of that class. PLADJ equals the sum of the number of like adjacencies for each patch type, divided by the total number of cell adjacencies in the landscape; multiplied by 100 (to convert to a percentage).

We used discriminant function analysis (DFA) to assess the ability of metrics of impervious surface detected at 5m to discriminate between different types of development at the parcel level. Discriminant analysis is a multivariate statistical procedure, which analyzes differences between mutually exclusive groups through linear relationships between variables to create the largest distance between the groups. The discriminant function is a linear combination of variables which produces a greater discriminating ability than did the original variables. Discriminant analysis also determines the relative contribution of each of the variables to the discriminating ability of the function.

We selected a stratified random from King County land parcels for the 6 major Land Use classes (N=30 per class) including Single Family Residential (SFR), Multi Family Residential (MFR), Commercial, Institutional, Industrial, Open Space. We then overlaid a 5x5 fishnet coverage and the parcel coverage over the orthophoto (Figure 2), and classified the percent impervious surface at 5 meter using visual interpretation.

The factors in the discriminate function included: (1) parcel area, (2) parcel distance to the three city business centers, (3) parcel percentage of impervious area, and (4) number of neighbor parcels of same land use type.

**Landscape Change**

We analyzed land cover changes within the Central Puget Sound region with elevations below 1000 meters, with a total area of 11,522 km2. Change in land cover was identified using the direct spatial comparison of classified images derived independently for each time period.

Classified images were overlaid to produce a thematic grid with a unique class for each change/no change scenario. Since direct pixel to pixel comparison is problematic considering registration and classification issues, we applied a rules-based approach stipulating that a pixel was considered changed based on an analysis of the trajectory of change. We develop the analysis at the regional level including the four counties of central Puget Sound, at the county level, and using a moving window of 150 meter resolution. This analysis was repeated for both the region, and the subareas of inside and outside the Urban Growth Boundary.

## RESULTS

Estimated land cover change models show that site attributes (i.e. land cover), site location (i.e. distance to forest areas, distance to critical areas and proximity to roads) and spatial patterns (i.e. dominance of land cover and forest patch size) all significant influence on land cover transition (Alberti and Hepinstall, forthcoming). Table 1 shows the logit model output for the transition of forest land to paved urban land. We used these preliminary estimated models to construct simulations of the land cover transitions between 1991 and 1999. A comparison with observed changes between 1991 and 1999 indicates good agreement between observed and predicted for Mixed Urban, Paved, and Forest classes with lower agreement for Grass/Shrubs/Crops and Bare Soil (Alberti and Hepinstall, forthcoming).

Different land use parcels can be discriminated using combination of land cover amount. Single-family residential parcels have significantly lower amount of impervious surface than multi family parcels, although these parcels may accommodate a much larger number of households. Even greater is the percentage of impervious surface on commercial and industrial parcels. It is important to notice the high variability of land cover composition within same land use types. These results show that land development typology have different impact on the amount of natural land cover that can be preserved and level of fragmentation that will generated under different land use scenarios. Parcel area, parcel distance to the city business centers, percentage impervious area, and adjacency to parcels of same land use type are the best discriminant for the six land use types types.

Using all the developed area in 1991 as a baseline, the area covered by development in Central Puget Sound in 1999 increased by 620±93 km2 representing 31.5% percent increase in developed land (Figure 4). Overall the region has added 5% of the total area to development. Forest cover has declined by 714±107 km2 a 10.3 percent decline over the same period and lost forest cover corresponding to 6% of the total land area (Alberti et al. forthcoming).

A great part of the land conversion to development has occurred in the low urban land cover class. Between 1991 and 1999, the low urban land cover class has increased from 872±131 km2 to 1281±192 km2, an increase of 46.9%. The high urban land cover has increased from 294±44km2 to 442±66 km2, an increase of 147.6±22.1 km2, approximately a 50%. About one third of the change in high urban has occurred between 1991 and 1995 and two-thirds between 1995 and 1999. A reverse trend can be observed in the medium urban land cover class, which has increased overall by only 64±10 km2, an increase of just 8%, which primarily occurred during the period 1991 and 1995. The medium urban land cover class declined by about 4% during the 1995 and 1999 period, indicating a densification of the urban area previously in a relatively less developed land cover class. Approximately two thirds of the decline in forest cover has occurred primarily in the period between 1991 and 1995, a loss of 481.9±72.3 km2 of forest cover. Another 232.2±34.5 km2 were lost between 1995 and 1999.

When measuring the landscape pattern at a 150m resolution, the urban land cover shows a slight decrease in the Aggregation Index and the Percent of Like Adjacencies Index between 1991, 1995, and 1999 (Alberti et al. forthcoming). However when looking at individual land cover classes a consistent increase in the aggregation of the high and low urban land cover can be observed across the overall region. The pattern is reflected in both the Aggregation Index Values and in the Percent of Like Adjacencies Index. The medium urban land cover however shows a decline in aggregation indicating a more dispersed pattern of medium urban cover. The forest cover shows an overall slight increase in both the Aggregation Index and the Percent of Like Adjacencies Index between 1991 and 1999 (Figure 5). Overall the Contagion Index has slightly declined while the Interspersion Index and the Shannon Index have increased in Central Puget Sound between 1991 and 1999 (Alberti et al. Forthcoming). However in order to interpret the changes in the landscape pattern it is critical to examine these metrics at a higher classification and spatial resolution.

The findings show significant changes in landscape composition and configuration over the eight-year period with an overall increase in urban growth and decrease in forest cover. However the data show a simultaneous intensification of the urban area (Alberti et al. forthcoming).

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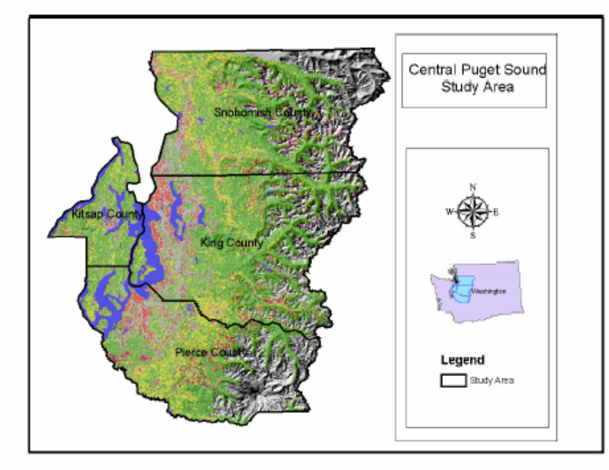


**Figure 1 Study Area**

| Land Use Variables | Coeff |
|---|---|
| Outside Urban Growth Boundary | -2.60 |
| Distance to all non-local roads | -1.89 |
| Development type Commercial | 1.18 |
| Development type Residential | -0.65 |
| **Land Use Change: Neighborhood Context** | |
| New development since 1991 | 2.25 |
| Commercial sqft added 1988-91 within 750m | 1.63 |
| **Land Cover/Landscape Composition** | |
| % Mixed Urban pixels within 150m | -4.59 |
| % Grass pixels within 150m | -5.16 |
| % >25% slope within 150m | -0.95 |
| % Water pixels within 150m | -4.21 |
| **Land Cover Configuration** | |
| Aggregation Index of Forest within 150m | 3.30 |
| Shannon Eveness of LC types | -1.95 |

**Table 1 Logit Model Output for Forest Cover to Urban**

**Figure 2 Fishnet of 5x5 m**

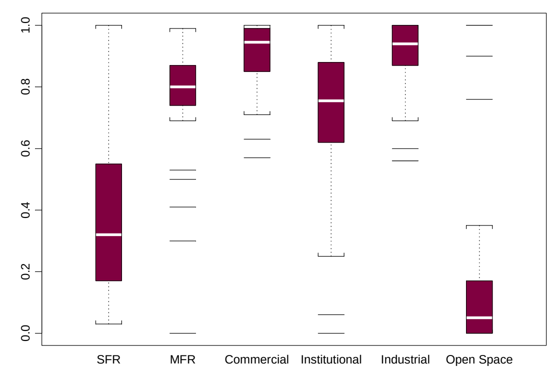


**Figure 3 Distribution of Impervious Surface by Land Uses**

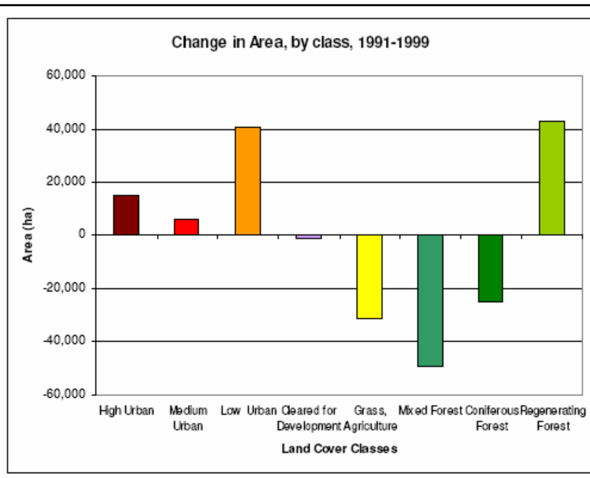


**Figure 4 Land Cover Change Puget Sound**

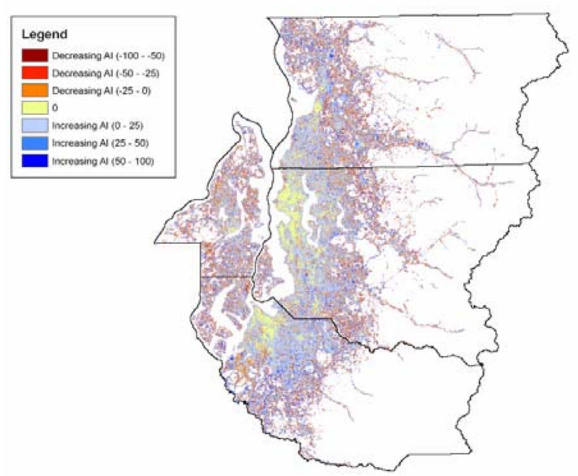


**Figure 5 Change in Aggregation Index of Urban Land**