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Urban hypotheses and spatiotemporal characterization of urban growth in the Treasure Valley of Idaho, USA

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ABSTRACT

Spatiotemporal patterns of urban growth can help identify impacts of urbanization, assess conceptual models of that growth, help predict future change, and inform associated urban management policies. Using multi-temporal spatial data (1938-2014), we categorized the newly urbanized area in Treasure Valley, Idaho into four urban growth forms and six urban land use classes. A time series analysis of new development revealed the existence of decadal-scale variability of urbanization at various levels of urban land use. Alternating dominance of dispersion and compaction processes were observed at the urban patch level. A similar periodicity was observed between edge-expansion and infill in terms of growth forms, and between residential and commercial development at the land use level. Our observations also indicate that recent urban densification is occurring in the Treasure Valley, similar to some other metropolitan regions in the United States.

1. Introduction

The world has witnessed rapid urban growth (UN 2011) with serious impacts on human health, environmental resources, biodiversity and climate ((Foley et al., 2005; Grimm et al., 2008)). Characterizing patterns of urban growth across the landscape and over time provides a foundation for assessing these impacts and investigating the processes that drive the growth (Seto & Fragkias, 2005). Quantification of these spatiotemporal patterns and linking them up with corresponding social and physical processes helps formulate effective urban land use policies (Wu, Jenerette, Buyantuyev, & Redman, 2011). Accurately traced trajectories of urban growth and its spatial patterns are also essential for developing a robust urban growth model (Dahal & Chow, 2014). Urban growth modeling, which entails simulation of spatial expansion of cities (or urban centers) over time and prediction of future scenarios of development (Clarke, Hoppen, & Gaydos, 1997; Li & Liu, 2007), contributes to the urban planning and sustainable development of cities (Triantakonstantis & Mountrakis, 2012). This study quantifies spatiotemporal patterns of urban growth using parcel-level spatial data, patch dynamics, gradient analysis and GIS techniques. The patterns are used to characterize historical and current urban land-use dynamics in the Treasure Valley of Idaho and discuss how those dynamics relate to, and inform, existing theories of urban growth.

1.1. Spatiotemporal characterization and test of urban hypotheses

'Urban growth patterns' refer to spatial characteristics of urban land in a specific geographic location over time. In this study, the term 'urban growth' is defined as the conversion of lands into built environment, and is used synonymously with 'urbanization'. The growth patterns are often quantified by using the methods of change analysis and application of spatial metrics (also called landscape metrics) to urban land patches (Herold, Scepan, & Clarke, 2002; Li, Li, & Wu, 2013; Lv, Dai, & Sun, 2012; Sun, Wu, Lv, Yao, & Wei, 2013; Taubenbock et al., 2014). A spatial change analysis typically involves detection and quantification of changes occurred in specific land use and land cover classes for a geographic region using longitudinal data (Inostroza, Baur, & Csaplovics, 2013). In a patch analysis, on the other hand, a range of metrics are used to characterize different aspects of land patches such as area proportions, density, edge, shape, isolation, connectivity and diversity (McGarigal, Cushman, & Ene, 2012; Rempel, Kaukinen, & Carr, 2012). Commonly used metrics include total class area (CA), percent of urban land to the whole landscape (PLand), number of

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patches (NumP), mean patch size (MPS), mean nearest neighbor distance (MNNDis), and largest patch index (LPI) (McGarigal, Cushman, Neel, & Ene, 2002). General patterns of landscape are inferred based on the metric values. In addition to identifying patterns, these metrics are computed to explore characteristics of urban fragmentation and to conduct gradient analysis of growth from different pull factors such as existing city centers, major roads, and coastlines (Aguilera-Benavente, Botequilha-Leitao, & Diaz-Varela, 2014; Fan & Myint, 2014; Seto & Fragkias, 2005; Taubenbock, Wegmann, Roth, Mehl, & Dech, 2009; Zhu, Xu, Jiang, Li, & Fan, 2006).

Spatial metrics and change analysis can also be used to explore morphological regularities of urbanization and test urban hypotheses. Specifically, the hypothesis that urbanization occurs in a wave like manner with two alternating phases of diffusion and coalescence (Dietzel, Herold, Hemphill, & Clarke, 2005; Dietzel, Oguz, Hemphill, Clarke, & Gazulis, 2005) has been widely studied. Taking the cases of two urban regions of the USA (central valley of California and Houston), the authors maintain that urbanization unfolds in a cyclical manner with a fluctuating prominence of diffusion (i.e. the emergence of new urban center or patches) and coalescence (i.e. the fusion of neighboring patches).

This hypothesis was examined by later studies. Xu et al. (2007) verified the occurrence of the wave-like rhythm of diffusion and coalescence in Nanjing metropolitan region of China by applying metrics including NumP and LPI to urban patches for five different years between 1979 and 2003. Yu and Ng (2007) computed eight landscape metrics for urban patches, concluding that urbanization in Guangzhou, China experienced a cycle of oscillation between diffusion and coalescence during the period of 1988 and 2002. Using about a century long time series spatial data, Tian and Wu (2015) found that Guangzhou of China experienced a diffusion-coalescence-diffusion-coalescence process while Phoenix of the United States experienced only a diffusion-coalescence process during the same period. Similarly, Aina, Van der Merwe, and Alshuwaikhat (2008), Nong et al. (2014) and Nassar, Blackburn, and Whyatt (2015) verified the hypothesis in the urban regions of Riyadh, Hanoi and Dubai respectively.

In contrast, Jenerette and Potere (2010) and Tian, Jiang, Yang, and Zhang (2011) refuted the hypothesis concluding that the diffusion-coalescence dichotomy represents endpoints rather than the alternate states. Wu et al. (2011), who conducted a comprehensive quantification of spatiotemporal patterns of Los Vegas and Phoenix urban regions of the USA, corroborated the hypothesis only partially.

Sometimes, urban growth is characterized by categorizing the newly developed urban patches into different growth forms (or types) such as infill, edge-expansion, and leapfrog in terms of the way urbanization unfolds in a given geographic region (Wilson, Hurd, Civco, Prisloe, & Arnold, 2003; Zeng, Sui, & Li, 2005). A few studies have analyzed the temporal dynamics of these growth forms in order to support the hypothesis of urban growth phases (e.g. Liu et al., 2010; Shi, Sun, Zhu, Li, & Mei, 2012; Sun et al., 2013; Xu et al., 2007). The authors observed a temporal oscillation in terms of total changed area of the three growth forms. Then, they equated the outlying development with diffusion phase and edge-expansion and infill development with the coalescence phase to support the hypothesis. Li et al. (2013), however, refuted the hypothesis stating that urbanization is not simply a dichotomous diffusion-coalescence switching process, but a “spiraling process of shifting dominance among the growth forms”.

A common trend among the mentioned studies was to base their analysis on urban patches, i.e. at the urban class level, primarily corresponding to the ‘Level-I’ class in Anderson, Hardy, Roach, and Witmer (1976), who provide an authentic framework of a national land use and land cover classification system. In doing so, they treat the whole urbanized area (or an urban patch) as a homogenous surface. But in reality, the urban land class (or an urban patch) is comprised of lower-order subclasses (hereafter ‘sub-urban’ classes but not to be confused with ‘suburban’ areas often described synonymously as sprawled development). For example, urbanized area (or an urban patch) can be further divided into multiple land units in terms of land cover types and functions they provide. Put differently, the ‘Level-I’ urban land class consists of second level land use classes such as residential, commercial and industrial (primarily corresponding to the ‘Level-II’ classes in Anderson et al. (1976)). Likewise, the ‘Level-II’ classes further consist of ‘Level-III’ classes. For example, residential land use comprises of single-family and multi-family classes. Since the existing research has solely focused on the analysis of either the urban patches or the growth forms to verify the hypothesis of urban growth phases, it would be interesting to investigate whether the ‘sub-urban’ level analysis of land use dynamics also reveals a similar rhythmic variability to support the hypothesis.

Another commonality among these studies is the use of land use and land cover data derived from Landsat images. Given a coarser spatial resolution, the ability of Landsat-derived datasets to capture details of urban fabric and detect meaningful patterns is heavily critiqued (Herold, Couclelis, & Clarke, 2005; Irwin & Bockstael, 2007). As data on urban extent are necessary to span about a century for capturing the full temporal rhythm of urbanization (Dietzel, Herold et al., 2005), the use of Landsat data has limitations from temporal perspective as well because they are available only since the mid-1970s. These observations suggest that finer scale spatial data over extended period of time must be used to adequately evaluate the alternating urban growth hypothesis.

In this study, we used parcel-level data for eight different time points (years) between 1938 and 2014. With the Treasure Valley of Idaho as a case of study, we computed a selected set of spatial metrics on urban patches. Newly developed urban patches during the seven change periods were categorized into three urban growth forms and six urban land use classes. Patterns at ‘sub-urban’ levels were characterized through change analyses based on the counts, total area, and average size of land parcels.

With this longitudinal analysis of the fine-grained cadastral data at the lower levels of urban land use, we also tested a relatively recent hypothesis of urban compaction variously termed as “new suburbanism” (Kotkin, 2005), “reurbanization” (Haase et al., 2010), the “death of the fringe” (Leinberger, 2011), “urban inversion” (Kane, York, Tuccillo, Gentile, & Ouyang, 2014) and “urban densification” (Delmelle, Zhou, & Thill, 2014). While differing in detail and individual nuances, these conceptual models share a common observation that metropolitan regions in the United States have recently witnessed an emerging trend of urban compaction. Urbanization in the post-WWII United States has been characterized by a low-density residential and leap-frog development termed ‘sprawl’ (Hanlon, Short, & Vicino, 2009). Taken synonymously with the images of suburbia, sprawl started to be heavily criticized for its social and environmental ills, thereby leading the advocates of new urbanism, smart growth, and sustainable city movements to raise serious concerns against it (Duany, Plater-Zyberk, & Speck, 2001). A trend of anti-sprawl and more compact development started emerging since the mid-1990s. Various studies have found empirical evidence to support this shift in the trend of urbanization.

Thomas (2008) observed that central areas of a few American cities obtained higher percentage of residential permits between 1990 and 2007, indicating on densification of inner urban areas. Nelson (2009) concluded that American metropolitan areas are transforming through ‘new urbanity’ which is characterized by growing residential density, infill development, mixed-land uses