Viewscape privacy drives exurban development

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# Abstract

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# 1. Introduction

***1. Exurban growth is uniquely characterized by aesthetic preferences and individual choice. One of those important preferences in privacy.***

Regions across the United States with scenic beauty and other natural amenities are experiencing rapid population growth and residential development. Exurban growth, or exurbanization, in particular in characterized by low-density residential settlement in rural areas valued for their aesthetic, recreational, and other consumption-oriented values (McCarthy 2008; Taylor 2011). A complex and varied picture of the drivers of exurbanization is emerging and the reasons that people move to scenic rural areas are as numerous as the communities that they form.

-For many exurbanites, natural amenities, such as scenic beauty, expansive vistas (Vukomanovic and Orr 2014), wilderness, recreational opportunities, and climate play an important role in in the decision to migrate. [ADD: Gosnell and Abrams 2011, McCarthy 2008; McGranahan 2008]

-Social and cultural connections to small-town rural life (Hines 2007) and a desire for a sense of community (Vogt 2011) can also be a draw for some exurbanites.

Privacy and solitude, often described as being unaware of other people when at home (Kondo et al. 2012), are important to many exurbanites who seek a seclusion or a “frontier living” experience (Hines 2007; Hines 2011). As many as 46% of amenity migrants in Washington State described finding “privacy” or “peace-and-quiet” as a primary purchase goal. Exurban development represents a unique land use often characterized by aesthetics - whether strictly related to perceptions of beauty or more broadly as principles or worldview expressed through outward appearance and actions - and driven by individual choice.

***2.  [AND] It’s a rapidly-growing land use with significant impacts to both communities and ecosystems. Impacts depend on the spatial distribution of development.***

a) area (and percentage) of land at exurban densities [and at other densities, for comparison]

b) how rapidly exurban areas are growing (e.g. rate of growth)

c) what are the land types that are converting to exurban

The per capita land conversion in exurban areas is much greater than for urban areas and that growth is seldom guided by growth management plans (Kondo et al. 2012). The rapid growth and dispersed nature of exurban development raises numerous ecological concerns, including changes to water quality and quantity [REF], altered fuel loads and fire regimes [REF], habitat fragmentation, and the spread of invasive species [REF].

-There are also impacts on communities (e.g. conflict between long-term residents and newcomers) - examples [REFS]

-Residential development drives the growth of other infrastructure and many of the ecological impacts of residential development depend on the spatial configuration of houses, associated infrastructure, in particular road networks (Vukomanovic et al. 2013; OTHER REFS). This spatial arrangement of houses depends on the drivers of exurbanization, where different preferences can lead to very different spatial arrangements

***3. [BUT] Studies to date have been largely descriptive or done at scales where you lose that individual perspective.***

-While work has been done to identify the drivers of exurbanization, very little is known about the spatial distribution of these preferences or the relative importance of some drivers relative to others.

-There have been limited attempts to integrate what has been learned directly from exurbanites about their reasons for moving to rural landscapes and the spatial pattern of development (Walker 2011). Interviews, survey, participant observation, focus groups, and other narratives provide valuable place-based information and context, however time and resource limitation make these approaches difficult to implement over landscape scales. Whether by norms of disciplinary practice or protocols designed to protect participant identity, reported results very seldom georeference narrative and survey data. Demographic and aggregated spatial analyses of the impacts and drivers of exurbanization have relied largely on country-level Census data (McGranahan 2008; Rudzitis et al. 2011), are valuable for understanding common drivers, such as climate (McGranahan 1999) or proximity to water (Mueser and Graves 1995), but miss individual perspectives. This earlier work is essential to identify what drivers to examine and questions to ask. However, these approaches limit our understanding of how preference are spatially distributed at finer scales, as well as the ability to ask questions about trade-offs.

***4. [THEREFORE] We turn to a viewscapes approach that is informed by social science, but relies on a spatial representation to understand the interactions and trade-offs between drivers.***

Analyses of demographic trends and

5. We a) mapped the historic distribution of suburban, exurban, and rural development prior to 2010 (great recession), b) analyzed size and privacy of exurban viewscapes relative to those in suburban and rural settings, c) we developed a predictive model of the probability of exurban settlements based on quantitative metrics of viewscape visual qualities. Application of the model is made possible by a new algorithm for computing spatially continuous, all-possible viewscape coverages for a region [highlight in abstract]

c) pro

To include in paragraph 5: The region is well-suited to studying drivers of exurban viewscape decisions as the rugged topography and low-height desert vegetation provide numerous scenic vistas AND local land-use policy does not restrict development of low-density housing and private roads.

Like much of the American Southwest, population growth is rapid…

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# 2. Methods

# 2.1 Study Region

The Sonoita Plain covers 700 km2 of southeastern Arizona with rolling hills ranging from 1100-1600 m in elevation in the Plain and steep terrain reaching 3000 m in the the Santa Rita and Huachuca Mountains. The natural landscape includes plant communities of desert grassland, plains grassland and desert scrub vegetation (Bock and Bock 2000; Figure 1). Residential development is concentrated in the central Plain where groundwater extraction from a single large aquifer is more available(Vukomanovic et al. 2013). Population of surrounding Santa Cruz County increased 46.5%, 45.1%, 29.3%, and 23.6% each decade from 1980 to 2010 (U.S. Decennial Census 2010), as rangelands and ranches made way for residential and limited commercial developments. With low cost of living, great scenic beauty, and plenty of available land, the Sonoita Plain became a booming housing market and destination for amenity migrants seeking new low-density residences and vacation homes. Local real estate companies highlight the region’s rural lifestyle, emerging winery/vineyard industry, and variety of recreational opportunities on public lands (Wildhorse Realty 2016; Sonoita Realty 2016).

The region is well-suited to studying drivers of exurban viewscape decisions as the rugged topography and low-height desert vegetation provide numerous scenic vistas AND local land-use policy does not restrict development of low-density housing and private roads. Land ownership is roughly 50% public (US Forest Service, Bureau of Land Management, State Lands) and 50% private (ASLD 2011), with almost all private land zoned for residential development (SCCZDC 2015). Sonoita Plain residents are generally older and wealthier compared to the state of Arizona, giving them greater mobility and freedom in their housing decisions. As a result of these factors, residential development in the area is driven more by individual choice than town or regional planning (reference).

# 2.2 Housing Data

We heads-up digitized the historic distribution of suburban, exurban, and rural houses in the Sonoita Plain study prior to 2010 using high-resolution (1-m) aerial imagery obtained from the USDA Farm Service Agency, National Agricultural Imagery Program (NAIP). We cross-referenced the digitizing with 2010 U.S. Bureau of the Census data to match the number of houses mapped to the number reported in each Census block. Using the same digitizing methods, we mapped the distribution of newly built homes between 2010 and 2016. Following Theobald (2005) and Leinwand, Theobald, Mitchell, and Knight (2010), we categorized homes as one of three housing-density classes: rural (0-0.0618 units/ha), exurban (0.0618-1.47 units/ha), and suburban (1.47-10 units/ha) (Figure X).

# 2.3 Line-of-Sight Viewscape Modeling

We calculated line-of-sight viewscapes for all 2XXX houses using  a 10-m DEM  [Source of DEM] and a computationally efficient line-sweeping algorithm implemented in r.viewshed module in GRASS GIS (Haverkort, Toma, & Zhuang, 2009). This DEM represents the highest-resolution elevation data available since publicly available LiDAR data do not exist for the study area. We set the observer height at 3 m above the surface to simulate a typical household viewpoint and we restricted the maximum visibility distance to 10 km in all directions. Though top-of-canopy (ToC) surface models derived from LiDAR data have been shown to more accurately model viewscapes in the presence of forest (Vukomanovic et al. 2018), this region is dominated by low stature desert plant communities. From the line-of-site visibility analysis , we  calculated four metrics of visual quality: viewscape privacy, size, greenness, and ruggedness.

It’s a line-of-sight, so the number of people that you can see = the number of people that can see you.

# 2.4 Statistical Analysis and Model Development

Using pairwise Wilcoxon rank sum tests, we compared differences in viewscape size and privacy between exurban,  suburban, rural, and randomly-located homes (built through 2010). Next, using autologistic regression, we tested which metrics of visual quality (viewscape privacy, size, greenness, and ruggedness) best predicted the probability of exurban development between 2010 and 2016. The autologistic form of ordinary logistic regression allowed our model to simultaneously account for expected spatial dependence in the housing data and avoid autocorrelated residuals (Besag, J., 1974, Gumpertz et al. 1997). We also considered the significance of a home’s proximity to a primary road to account for the potential importance of accessibility in remote locations. Our analysis included the examination of all-possible models testing every subset of predictors and identifying the best model based on Akaike Information Citerion (AIC) (*sensu*[Quinn & Keough 2002](http://onlinelibrary.wiley.com/doi/10.1111/j.1365-2745.2006.01206.x/full#b52)).

# 2.5 Model Application with spatially continuous, All-Possible Viewscapes

Within our study area we created a regular grid of viewpoints with 30m spacing and computed viewsheds for each of these viewpoints using the 10-m DEM.The resulting 30-m resolution total viewshed was then derived by storing the number of visible cells from each view point rather than using raster algebra to add each individual viewshed one at a time (Llobera et al, 2010). Based on the computed viewsheds, we derived several variables for each viewpoint - viewshed size, the number of visible houses, greenness based on NDVI, and terrain ruggedness. By assigning each of the individual computed values on the grid, we created several 30-m resolution raster layers representing spatially continuous visual attributes of the landscape - visual prominence (Llobera 2003), privacy index, greenness, and terrain complexity, respectively.

Since deriving the total viewshed and other visual attributes for our study area required to compute 40000 individual viewsheds, we parallelized the computation in high-performance computing environment to reduce the required time from several months to several days. (I can add more precise numbers if needed). The individual viewshed computations were performed using GRASS GIS module r.viewshed with 3-m observer’s height and while considering the curvature of the earth. Since the maximum visibility distance was set to 10 km in all directions, we sufficiently increased the extent of the DEM to avoid any edge effects.

For each 30-m pixel, computed the viewscape geometry and a value for each of the considered variables (privacy, greenness, terrain ruggedness, viewscape size, and primary roads). [Figure DD can show the number of neighbors visible from each pixel based on it’s size and configuration]

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# 3. Results

Our heads-up digitizing identified a total of 1,867 homes in 2010 (5X% exurban). Exurban homes built prior to 2010 have significantly larger viewscapes than randomly-distributed (Z times on average), suburban (X times on average), and rural (Y times on average) homes (Figure BBa). These same exurban homes were visible to significantly fewer neighbors compared to suburban homes, but more visible than rural homes. Exurban homes were also visible to XX fewer neighbors than what may be expected by chance (Figure BBb).

An additional 2XX homes were built between 2010 and 2016 with XX% located in low density exurban and rural settings. T-test show that exurban homes built after 2010 had significantly larger viewscapes (P < 0.00X) but possessed less privacy (P< 0.00X) as the region grew. The auto-logistic model of new growth showed that viewscape privacy (P = 0.003) and NDVI (P < 0.001) were the most significant predictors of the probability of exurban development between 2010 and 2016 (write equation here). Proximity to primary roads and the size and ruggedness of exurban viewscapes were not significant predictors after accounting for privacy and NDVI. Application of the model in the GIS produced a predictive map of the exurban development probability across the study region (Figure DD).

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# 4. Discussion

1. Exurban viewscapes are larger, but they see fewer neighbors

Would expect random homes that are “pushed” to the edges of the study area to have larger viewscapes. Supports findings in Vukomanovic and Orr (2014) about the importance of visual scale as a visual quality metric.

2. The fact that they see fewer neighbors suggests an optimization

3. The all-possible(“total”) viewscapes

-Results

-What they mean

-How they can be applied

4. People have done a lot of work to understand individual (or a small number of drivers). As that understanding has grown, understanding trade-offs in preference is the next step. This is a unique way that geospatial approaches can contribute…in survey and other social science methods, difficult to ascertain trade-offs (plus memory fades with time). Contribute to understanding of amenity migration with this approach.

Location matters and the spatial configuration of exurban houses, roads, and associated infrastructure will depend on the drivers of migration. Different patterns of exurban growth will have different impacts on both ecosystems and rural communities. In area places where land availability allow choice with regard to house location, information about landscape drivers and exurban preference could prove helpful for infrastructure planning and growth management efforts.

scrap: Homes built through 2010 represent a period of first gradual (1970-XXXX) and then rapid (XXXX) growth, which virtually came to a stop with the great recession. This pre-2010 period of housing growth represents a wide-range of drivers, while XX% of the new homes after 2010 has been exurban.

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# Figures:

Figure AA: Study Area Map

Figure BB: Photos of exurban development

Figure CC: a) Viewscape Size by Density Class; b) Privacy by Density Class ) [do 3 pairwise Wilcoxon tests and include bar graph (include the statistics in the caption)]

Figure DD: Spatially continuous, all-possible viewscapes visualization: a) viewscape size, b) privacy, c) greenness, d) terrain ruggedness

Figure EE: Predictive map of the probability of exurban home development (INCLUDE EQUATION AGAIN SO FIGURE STANDS ON ITS OWN). *Locations with the highest likelihood of exurban development occur in places that exhibit opportunities to A) view the scenic beauty of vegetated “green” landscapes….., B) build in highly private, low density settings, and c) the combination of green and private viewscapes.*

Jelena To-Do:

-Figure BB and the wilcoxon tests

SCRAPS:

The region provides a unique opportunity for studying drivers of exurban viewscapes as the surrounding mountains provide scenic vistas with vertical visual boundaries that constrain residents’ views to the interior of the Plain and the inward-facing mountain slopes

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