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Article

Landscape Aesthetics and the Scenic Drivers of Amenity Migration in the New West: Naturalness, Visual Scale, and Complexity

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Abstract: Values associated with scenic beauty are common "pull factors" for amenity migrants, however the specific landscape features that attract amenity migration are poorly understood. In this study we focused on three visual quality metrics of the intermountain West (USA), with the objective of exploring the relationship between the location of exurban homes and aesthetic landscape preference, as exemplified through greenness, viewshed size, and terrain ruggedness. Using viewshed analysis, we compared the viewsheds of actual exurban houses to the viewsheds of randomly-distributed simulated (validation) houses. We found that the actual exurban households can see significantly more vegetation and a more rugged (complex) terrain than simulated houses. Actual exurban homes see a more rugged terrain, but do not necessarily see the highest peaks, suggesting that visual complexity throughout the viewshed may be more important. The viewsheds visible from the actual exurban houses were significantly larger than those visible from the simulated houses, indicating that visual scale is important to the general aesthetic experiences of exurbanites. The differences in visual quality metric values between actual exurban and simulated viewsheds call into question the use of county-level scales of analysis for the study of landscape preferences, which may miss key landscape aesthetic drivers of preference.

Keywords: amenity-migration; exurbanization; residential development; aesthetic drivers; viewshed analysis; greenness; terrain ruggedness; Arizona

1. Introduction

Rural regions throughout North America and Europe are progressing through a striking and sustained post-industrial transition [1–3]. The emphasis has changed from material production and extractive industries to the production and consumption of experiences [3,4]. Across the United States, amenity-rich regions are experiencing rapid land-use change in the form of low-density residential development or exurbanization. Exurbia, as both physical space and social phenomenon, describes very-low-density, amenity-seeking, post-productivist residential settlement in rural areas [3]. This settlement is often spurred by amenity migration, which refers to "the purchasing of primary or secondary residences in rural areas valued for their aesthetic, recreational, and other consumption-oriented use values" [5]. In the United States, exurban land use occupies five to seven times more area than land with urban and suburban densities, and has increased at a rate of about 10% to 15% per year [6,7].

The American West, long characterized by open spaces, low population densities, and the dominance of primary sector activities, such as mining, logging, and ranching, is experiencing high rates of population growth related to amenity migration [8–11]. Extractive and manufacturing activities that were once at the center of western economics are now overshadowed by service-sector and high-tech industries [10–13]. In the New West, scenic landscapes are increasingly valued more for the aesthetic and recreational amenities they provide than for mineral resources, forage or timber [12,14–18]. Amenity migration to the ranching landscapes of the American West has largely driven the transformation of rangelands from low-value productive lands to high-value positional goods [11]. A study of ranching activities in southern Arizona points to a combination of low-density residential development, specific tax policies, and the commodification of the ranching lifestyle idyll in the transformation of rural landscapes [19].

The post-industrial transformation of rural economies reflects both economic forces and societal concerns about extractive uses in threatened landscapes. However, it is not clear to what extent amenity-based communities and the environmental conditions and aesthetics that they have come to enjoy can be sustained. As residential development drives the growth of infrastructure and nearby commercial developments, the number and complexity of land-use transitions tend to increase, and with them, the potential for detrimental impacts [20]. Despite its large spatial extent, exurbanization is seldom guided by growth management plans [21] and has received much less study than land-use change in suburban or urban areas [17].

The rapid and dispersed nature of exurban development raises numerous ecological concerns, including reduction of water availability to biota, habitat fragmentation, disrupted fire regime, alteration of the food network, and change in vegetation owing to invasive species [17,22–24]. Houses, roads, and other infrastructure have impacts on ecological processes beyond their physical boundaries. Some modifications, such as mowing grass around houses, are immediately obvious, whereas others may manifest far off-site and substantially lagged in time, such as the slow transport of road-related pollutants into ground water systems [25]. Findlay and Bourdages [26] found that the full effects of road construction (restricted movements, increased mortality, habitat fragmentation, edge effects, invasion by exotic species, and increased human access to wildlife habitats) on wetland biodiversity may be undetectable in some taxa for decades. Populations of many species of large wildlife, including wolves [27,28] and mountain lions [29] only thrive where road density is less than 0.6 km/km^2. The spatial arrangement of houses, and their associated infrastructure, therefore has important implications for ecosystem function.

The drivers of exurbanization are numerous, and people move to rural areas for a variety of economic and non-economic reasons. Drivers include both push- (crime, crowding, poor education systems, *etc.*) and pull- (affordable or desirable housing, privacy, better schools, *etc.*) factors [30]. These drivers have been augmented by technological advancements and increases in tele-commuting [31], and transportation and road-network improvements [32]. In the case of amenity migrants, studies have shown that non-economic pull-factors are often most important [33]. Social and cultural connections to small-town rural life can be a draw for some amenity-migrants [34,35]. For many exurbanites, natural amenities, such as scenic beauty, expansive vistas, wilderness, recreational opportunities, and climate, play an important role in the decision to migrate [5,13,36].

1.1. Natural Amenities and Visual Quality

A variety of factors contribute to making the movement of affluent urban populations to scenic rural areas desirable. Values associated with quality of life, proximity to nature, and recreation are the common “pull factors” described in the amenity migration literature [14,17,33,37]. Wilderness areas, in particular, have proven to be a major draw for in-migrants [38–40], many of whom speak of the “one-hour rule”—they want to work within an hour’s drive of good fishing, skiing, and hiking [17]. Surveys of new residents and businesses in rural counties with high levels of natural amenities found that factors such as scenery, environmental quality, recreational opportunities, and climate were more important reasons for relocation than job opportunities or cost of living [8,17,41].

Work has been done to identify the drivers of exurbanization, but very little is known about the spatial distribution of these preferences. The specific features of the environment that attract amenity migration are poorly understood and the relative contributions of different visual quality elements to the appeal of an area are unclear. The visual quality literature is vast and many visual quality concepts or indicators have been identified (reviewed in [42]). Here we focused on three landscape visual-quality concepts that are likely important in a semi-arid grassland system in the intermountain West (USA), with the objective of exploring the relationship between house location selection and these indicators of visual quality. The three visual quality concepts are naturalness, visual scale, and complexity; respectively, these concepts were assessed by the following metrics: greenness, viewshed size, and terrain ruggedness. Different drivers could mean different spatial arrangements of homes and therefore different impacts on both social systems and ecosystem function. A better understanding of the factors that drive amenity-migration can help set the stage for research that explores the spatial patterns of exurban development.

1.1.1. Naturalness: Greenness

The widespread aesthetic preference for natural elements and settings is a well-documented phenomenon, covered by a vast literature and substantiated by well-controlled research [42–44]. As a concept, naturalness is generally used to describe how close a landscape is to a perceived natural state. Perceived naturalness can thus be different from quantitative ecological definitions of naturalness [45,46]. Vegetation or greenness is an important element of naturalness and has been found to enhance landscape preference [47–49].

One of the important draws of natural settings is that they offer excellent opportunities for relaxation and restoration from stress [50–52]. Studies have also found that greenness is positively associated with self-reported health [53,54], physical activity [55–58] and mental health [54,59,60]. Nature also plays an important role in the vision of the rural idyll and exurbanites often have the cultural, political, and economic capital to force this vision to the top of the public agenda [21,34,35]. Increased greenness raised the sale prices of ranchettes in Yavapai County, Arizona [61]. The concept of "greentrification" has been introduced to the study of rural gentrification [62], drawing attention to the importance of ideals of nature to rural in-migrants and highlighting the way that natural rural spaces have become high-end consumptive commodities.

1.1.2. Visual Scale: Viewshed Size

Theories relating to visual quality and landscape preference strongly emphasize the concept of visual scale. Visual scale is related to the degree of openness in the landscape [42] and is affected by line-of-sight and viewable area. Research on landscape preference has consistently found that people like traversable foregrounds and open vistas [63] and that the degree of openness is directly related to landscape preference [64–66]. In prospect-and-refuge theory [67], prospect is used to describe the degree to which the environment provides opportunity, which is claimed to be important in landscape preferences. The prospect element predicts that humans should be attracted to broad, unoccluded vistas and the degree of prospect has been described as the depth and aerial extent of the view [68]. Other studies have used openness as an indicator and have defined it as the ease with which an observer can obtain an extensive view over the landscape [69]. Viewshed size measures the extent of the view, providing a method to compare visual scale and openness.

1.1.3. Complexity: Terrain Ruggedness

Complexity has been identified as a key component of visual quality and is defined as the diversity and richness of landscape elements and features [70,71]. Complexity can be thought of as the number of different visual elements in a scene or the intricateness of the scene [71] and is important for landscape preference [72]. Although few studies have focused on what actually constitutes complexity with regard to landscape elements and how these elements relate to preferences [42], complexity is a visual concept for which there has been an active development of indicators, both in relation to landscape ecology and visual preference [73–76]. One such indicator is topographic heterogeneity or terrain ruggedness, which was selected by the US Department of Agriculture Economic Research Service (USDA-ERS) as one of three physical factors that represent the base ingredients of natural amenities [77]. In general, more varied or rugged terrains are considered more appealing [36,71,72,78]. Population growth has been shown to be positively correlated with mountainous topography in the rural counties of Idaho, Montana, and Wyoming, USA [17].

1.2. Preference Scale and Viewshed Analysis

Much of the work on the impacts and drivers of exurbanization has been done on the county-scale, relying largely on census data [2,17,36,79]. The USDA-ERS has proposed a county-scale "natural amenities index" based on three classes of physical factors: climate, topography, and water area [77]. These factors were selected as representing the base ingredients of natural amenities, and population growth in rural counties in the United States was strongly correlated with this natural amenities index from 1970 to 1996 [78]. Any given area is bound to have numerous settings and viewpoints of varying scenic quality [74]. When counties are the units of analysis in landscape preference, individual viewpoints or scenes are not assessed, but rather the interest is in the general capacity of each county to yield scenic beauty. This approach is supported by the finding that regional landscape features are important for housing value independently of the particular setting of a housing unit [80].

Although informative of broad trends, county-level scales of analysis are too coarse to study the specific features of the environment that attract amenity migration. For example, previous studies that included topography as a preference metric divided the entire United States into five topographic categories, with a four-category scale of relief within each general topography type [36,77,78]. At this scale of analysis, entire counties fall within a single topographic category. In order to study the relative importance of visual quality drivers, the spatial distribution of exurban development requires analysis on a finer scale. By exploring the relationships between house location and visual quality metrics, we get more information about landscape preference. Analysis at the viewshed scale allows us to tease apart visual quality metrics and study the relative contributions of different visual quality elements to the desirability of an area.

A viewshed is composed of the areas of land, water, and other environmental elements that can be seen from a fixed vantage point [81,82]. The most common uses of viewshed analysis include visual exposure [83,84], archeological research [85], and photo-elicitation/landscape-classification [86,87]. To our knowledge, viewshed analysis has not been used previously in the study of housing location choice. Viewshed analysis allows assessment of what is visible from where people actually chose to live, allowing for a much finer-scale study of preference.

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 actual exurban development [88]. There is also a lack of systemic studies that examine the relationships between visual indicators and house location. The objective of this paper is to explore the relationship between the location of exurban homes and aesthetic landscape preference, as exemplified through three visual quality metrics, using viewshed-based geographical representation and analysis. In examining the physical distribution of actual exurban homes, we can gain a better understanding of the aesthetic preferences that drive house location selection in the Sonoita Plain.

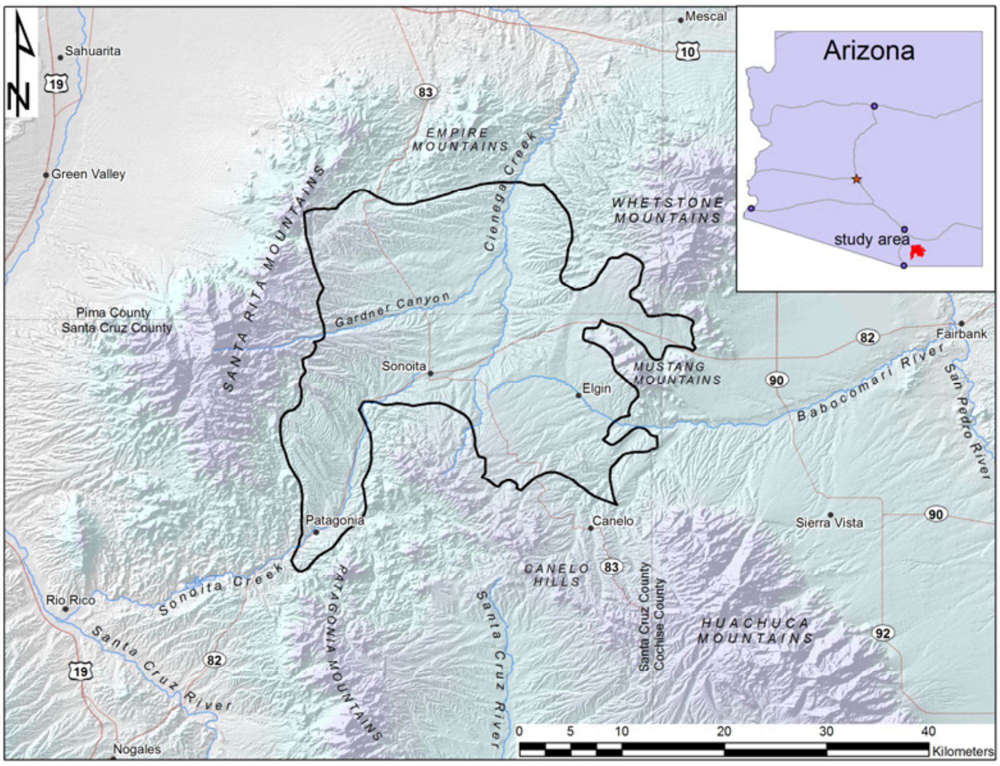
We begin by describing the Sonoita Plain, southeastern Arizona, USA, a study area that provides a buffered region of exurbanization, ideal for understanding spatial patterns with limited external influences. This is followed by a description of the spatial viewshed analysis used to assess the influence of greenness, viewshed size, and terrain ruggedness on the spatial pattern of exurban development. We finish with an analysis of results and their broader implications.

2. Study Area and Methods

2.1. Study Area

The Sonoita Plain (696 km^2) lies in a predominantly semiarid grassland located in northwestern Santa Cruz County, Arizona, USA (31°32′44″N, 110°28′44″W). The Sonoita Plain is surrounded by the Santa Rita Mountains to the west, the Huachuca Mountains to the south-east, the Empire Mountains to the north, the Whetstone Mountains to the northeast and the Canelo Hills to the south (Figure 1). Elevations range from about 1100 to 1600 m in the central Plain, while elevations of upland areas approach 2900 m [89]. This constrained geographic area is entirely ringed by mountains that provide vertical visual boundaries. The unique topography makes this area especially well-suited to viewshed analysis since the mountains effectively constrain what is visible to those living in the Sonoita Plain to the interior Plain and the sides of the mountains facing the Plain, reducing the risk of potentially confounding influences beyond the mountains.

Figure 1. Map of the Sonoita Plain, highlighting the mountains surrounding the study area.



The Sonoita Plain is acknowledged to be a prime example of high plain southwestern grassland [90]. It is largely characterized by desert grassland, plains grassland and desert scrub communities (501 km^2/72% of study area), with some riparian forest and riparian woodland communities along Cienega Creek in the northern part of the study area (22 km^2/3% of study area) [91]. Upland regions ringing the central Plain are dominated by oak communities (172 km^2/25% of study area) [91], while agricultural and developed areas (3 km^2/0.4% study area) are located near towns [92]. Mean temperatures range from a January minimum of −2 °C to a June maximum of 33 °C (1971–2000), and average annual rainfall is 460 mm, with more than 50% occurring during the summer (July to September) monsoon [93]. Much of the Sonoita Plain has not burned within historic fire return intervals, suggesting an accumulation of organic fuels [24].

As the Sonoita Plain is entirely ringed by mountains, we delineated the study area to include the interior of the Plain using an impervious surface layer developed by the Water Resources Research Center, University of Arizona for the state of Arizona. The imperviousness of the substrate was selected as the defining study area characteristic because it has important consequences for the availability of water. Wells are mostly limited to the unconsolidated material of the Plain, with a handful of wells drawing water from shallow aquifers in the mountains. Given that ground water is the sole source of potable water in the area, this delineation corresponds well to human settlement in the area. The Sonoita Plain was classified as either pervious (unconsolidated material/soil) or impervious (rock) and the area inside the delineated "study area" outlined in Figure 1 corresponds to unconsolidated material/soil. This delineation separates the study area from communities on the other sides of the mountains and was primarily used to constrain the locations of simulated housing distributions. Here, "Sonoita Plain" and "study area" are used interchangeably to describe the interior of the Plain, as shown in Figure 1.

In recent years, residential developments have sprung up on land historically used for cattle ranching. People are relocating to the Sonoita Plain in increasing numbers and houses are being constructed as vacation homes, retirement homes, and primary residences for those who commute to jobs in the nearby municipalities of Tucson, Nogales and Sierra Vista, Arizona. The median income, median house value, percent of residents with incomes below the poverty line, and median age in 2010 for the Sonoita Plain (towns of Sonoita, Elgin, and Patagonia, and surrounding census blocks), Santa Cruz County, Arizona and the entire state of Arizona (US Bureau of the Census) are shown in Table 1. Overall, the residents of the Sonoita Plain are older and wealthier than the residents of the rest of Santa Cruz County or the state Arizona overall. These trends are in keeping with those observed for amenity-migrants elsewhere [1,2] and suggest the ability or freedom on the part of Sonoita Plain exurbanites to make choices about housing location. Residential development in this area has been individual-driven, rather than the result of planned communities.

Table 1. Comparison of income, house value and resident age in the Sonoita Plain, Santa Cruz County, AZ, and the state of Arizona.

2010 Census Figures	Median Household Income ($)	Median House Value ($)	Income Below Poverty Level (% Population)	Median Age (Years)
Sonoita Plain, AZ	62,984	368,421	6.1	58.0
Santa Cruz County, AZ	35,707	125,907	24.5	31.8
Arizona	48,745	187,700	13.9	34.2

2.2. Methods

2.2.1. Deriving Contextual Variables

Population data from the US Bureau of the Census are tied to the primary residence and such measures can underestimate landscape changes because vacation and second homes are not represented. Therefore, housing density is a more complete and consistent measure of landscape change than population density [7]. In lightly-settled landscapes, houses are not evenly distributed across large census blocks, and census-based housing-density measures do not capture real location distributions. To address this, the locations of all houses in the Sonoita Plain study area were manually digitized from 2010 high resolution (1 m) aerial imagery obtained from the USDA Farm Service Agency, National Agricultural Imagery Program (NAIP). These locations were cross-checked against 2010 U.S. Bureau of the Census data to ensure that the number of homes digitized in each census block matched the number of homes reported in the 2010 US Census. By mapping the actual location of each house, a representation of how houses are distributed across the landscape emerges. Road information and town locations were obtained from 2010 census data (U.S. Bureau of the Census) for Santa Cruz, Cochise, and Pima counties in Arizona. The elevation model used was the 1/3-arcsecond digital elevation model provided by the U.S. Geological Survey [89].

In 2010, the Sonoita Plain had 1867 homes (U.S. Bureau of the Census) and supported three different housing-density classes. Following previous work [7,94], the study area was divided into the following housing-density classes: rural (0–0.0618 units/ha), exurban (0.0618–1.47 units/ha), and suburban (1.47–10 units/ha). This study focuses on those houses classified as exurban; of the 1867 total houses in the study area, 998 are exurban.

2.2.2. Viewshed Analysis

Viewshed analysis identifies the cells in an input raster that can be seen from an observation point. Starting with the cells closest to the observation point and working outward, a line-of-sight process calculates and maps whether the cell can or cannot be seen. As long as the tangent increases in the line-of-sight from the observation point, the cell is visible; if the tangent decreases, the cell is not visible [81,82]. Using elevation data as the input, each cell in the output raster that can be seen from the observation point is given a value of one, while all of the cells that cannot be seen from the observation point are given a value of zero. In our viewshed analysis, each exurban house served as an observation point and the viewshed for each house represents the portions of the landscape visible from that location. We calculated the viewshed of each of the 998 exurban homes in the Sonoita Plain. The vantage-point was not restricted, meaning that we considered the view in all directions around each home. When combined with additional metrics, such as greenness, viewshed size, and terrain ruggedness, viewshed analysis allows comparison of the landscape characteristics visible from each vantage point.

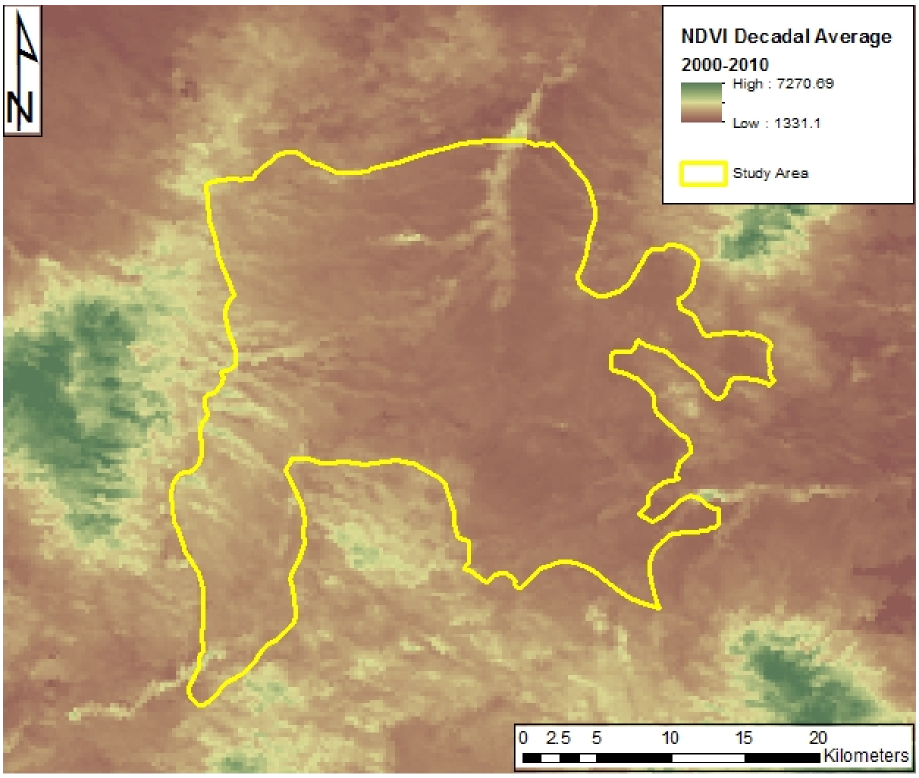
2.2.3. Greenness

The Normalized Difference Vegetation Index (NDVI) provides a measure of greenness that can be summarized and applied across different areas of interest for comparison [95]. The principle underlying NDVI is that healthy green vegetation reflects more infrared radiation and absorbs more energy in the red wavelength than unhealthy vegetation or sparsely- and non-vegetated surfaces. NDVI is calculated according to the following algorithm: NDVI = (NIR − RED)/(NIR + RED), where NIR is the amount of near-infrared wavelength reflectance and RED is the amount of red wavelength reflectance detected. Scores range from −1 to 1, where −1 indicates that no vegetation is present and 1 indicates dense amounts of healthy vegetation [95].

NDVI has been widely used to assess levels of vegetation in agriculture and land-use/land-cover change research [96–98]. Recent studies have also used NDVI to look at the relationships between neighborhood greenness and health [58,99,100]. The correlation between NDVI scores and the observed residential greenness ratings of environmental psychology experts is high, indicating that NDVI is a useful measure of perceived greenness [101].

We used the Version 5 NDVI product collected by the Moderate Resolution Imaging Spectroradiometer (MODIS) aboard the Terra platform (horizontal 8; vertical 5) at a 250 m resolution. The NDVI product is multiplied by a scale factor of 0.0001 for a range of −10,000 to 10,000. We calculated a decadal average value for each pixel by summing all of the NDVI values from 2000 to 2010 and dividing by the number of images (249) (Figure 2). The viewshed for each exurban house, as well as for each simulated (validation) house, was overlaid on the decadal average NDVI surface. The NDVI values that fell within each viewshed (*i.e.*, are visible from that house) were averaged to calculate a mean viewshed NDVI value.

Figure 2. 2000–2010 decadal average NDVI values for the Sonoita Plain.



2.2.4. Viewshed Size

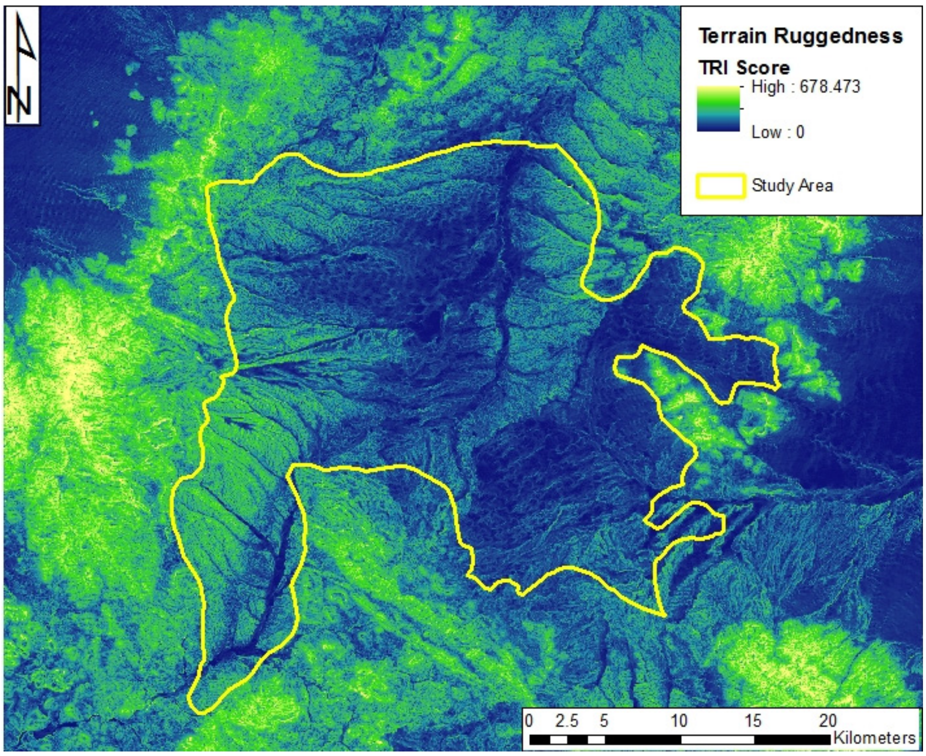
Viewshed size provides a measure of how constrained or expansive the view is from each vantage point. The number of 30 × 30-meter pixels (DEM layer resolution) in each viewshed was tabulated to calculate the size of the viewshed.

2.2.5. Terrain Ruggedness

The Terrain Ruggedness Index (TRI) provides a quantitative measure of terrain heterogeneity and allows for comparisons between areas [102]. Originally developed to assess the effects of terrain heterogeneity on wildlife abundance, the TRI is derived from digital elevation models (DEM) using a terrain analysis function implemented in a geographic information system. The TRI index has since been used for animal habitat mapping and analysis [103–105], connectivity analysis [106,107], and movement ecology [108,109].

The TRI is computed for each grid cell of a DEM by calculating the sum change in elevation between the central grid cell and the mean of an 8-cell neighborhood of surrounding cells. The equation is TRI = $\sqrt{|(maxDEM)^2 - (minDEM)^2|}$ [102]. Two 3 × 3 neighborhood rasters were created from the DEM: maximum value (maxDEM) and minimum value (minDEM). A raster calculator was then used to compute the TRI for each cell of the study area using the two neighborhood inputs (Figure 3). The viewshed of each exurban house, as well as of each simulated (validation) house, was overlaid on the TRI surface. The grid cell-level TRI values that fell within each viewshed (*i.e.*, are visible from that house) were then averaged for a total TRI. We also calculated the maximum TRI value in each viewshed.

Figure 3. The Terrain Ruggedness Index (TRI) represents terrain heterogeneity in the Sonoita Plain (Index range is 0 to 4367 m).



The TRI was originally developed for state-level analysis in Montana (USA); this area includes the Rocky Mountains, and the TRI classification categories reflect the extreme ruggedness of that terrain (Table 2). The TRI categories were assigned using the equal area classification method to group continuous ranges of TRI values into seven classes of unequal range, but equal area [102]. Our study area does not yield the full range of values possible. Terrain ruggedness in the Sonoita Plain ranges from "level" to "highly rugged", with the highest TRI values at 678.5 m (Figure 3). Although the TRI categories are informative, the continuous distribution of values, rather than the categories, was used to compare the actual exurban houses and the simulated (validation) houses.

Table 2. Terrain Ruggedness Index (TRI) Categories (from Riley *et al.* [102]).

Category	Elevation Difference (m)
Level	0–80
Nearly Level	81–116
Slightly Rugged	117–161
Intermediately Rugged	162–239
Moderately Rugged	240–497
Highly Rugged	498–958
Extremely Rugged	959–4367

2.2.6. Validation

In order to test whether the findings for each of the three visual quality metrics (greenness, viewshed size, and ruggedness) reflect location choice on the part of homeowners, we tested the actual exurban distribution against a simulated, random house-location distribution. Following previous work [7], the study area was divided into "developable" and "undevelopable" areas, with Bureau of Land Management (BLM), State, US Forest Service, and Nature Conservancy lands classified as "undevelopable", while private lands were deemed "developable". Land ownership data from the Arizona State Land Department (ASLD) [110] shows that land ownership in the study area is roughly 50% public and 50% private. The ASLD land ownership data was crosschecked against hardcopy maps from the Santa Cruz County Assessor's Office. One discrepancy was found and a single parcel was changed from "private" to "BLM" ownership to match the finer-scale information from the Santa Cruz County Assessor's Office. We simulated a random house location distribution on portions of the study area deemed "developable". The simulated distribution included 998 houses, which matched the number of actual exurban houses in the study area. We calculated the viewshed of each house in the simulated distribution and performed the calculations outlined above for each of the visual quality metrics.

We performed two-sample Kolmogorov-Smirnov (K-S) tests to compare the cumulative distribution functions (CDFs) of the two data sets (actual exurban homes and simulated house distribution). The two-sample K-S test was used to test whether the two probability distributions differ. The Kolmogorov-Smirnov statistic is defined as $D_{n,n'} = \sup_x \left|F_{1,n}(x) - F_{2,n'}(x)\right|$, where $F_{1,n}$ and $F_{2,n'}$ are the distribution functions of the first and second sample respectively [111]. In total, four tests were performed: average NDVI, viewshed size, total (average) TRI, and maximum TRI. The result h is 1 if the test rejects the null hypothesis (same continuous distribution) at the 5% significance level;

otherwise it is 0. The test statistic k is the maximum difference between the curves [111]. The two-sample K-S test is distribution free and valid for testing data against any continuous distribution [112].

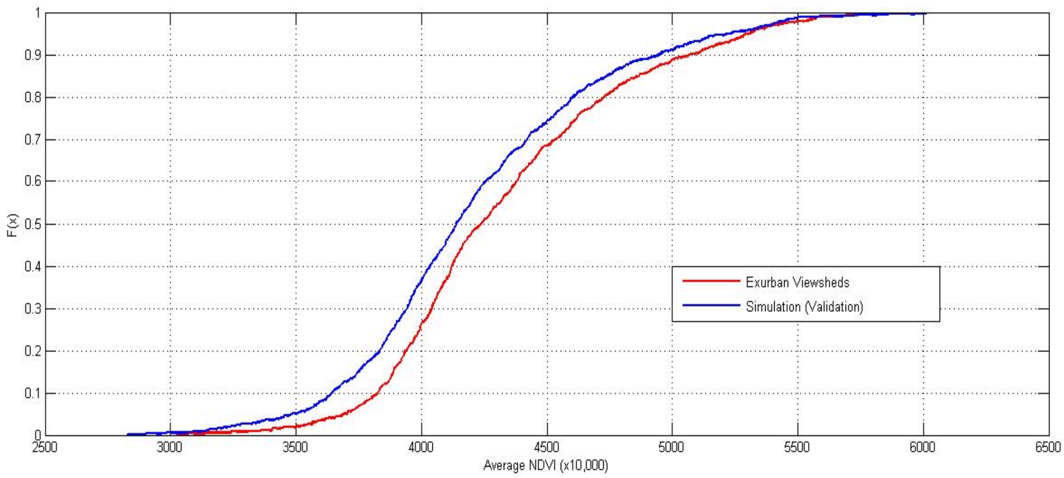
3. Results and Discussion

3.1. Results

3.1.1. Greenness

We performed a two-sample Kolmogorov-Smirnov (K-S) test to compare the cumulative distribution functions (CDFs) for average NDVI of the actual exurban houses and the simulated houses (Figure 4). The CDF describes the probability that a real-value variable X, in this case average NDVI, with a given probability distribution will be found at a value less than or equal to x [113]. It can be thought of as the "area so far" function of the probability distribution. For example, 10% of the simulated houses are accounted for by the time the distribution reaches an average NDVI value of 3640.26, while 10% of exurban houses have average NDVI values below 3824.70. The exurban houses have viewsheds with higher average NDVI values than do the simulated (validation) houses. A p-value < 0.0001 indicates that the results are significantly different at the predetermined significance level of 0.05 (h = 1 if $p < 0.05$) (Table 3). The actual exurban households can see significantly more vegetation than would be expected if the houses were placed randomly and without consideration for greenness. The sigmoid shape of the curve indicates a normal distribution for both the actual exurban and simulated distributions.

Figure 4. Cumulative distribution functions of average NDVI values for actual exurban and simulated (validation) houses.



3.1.2. Viewshed Size

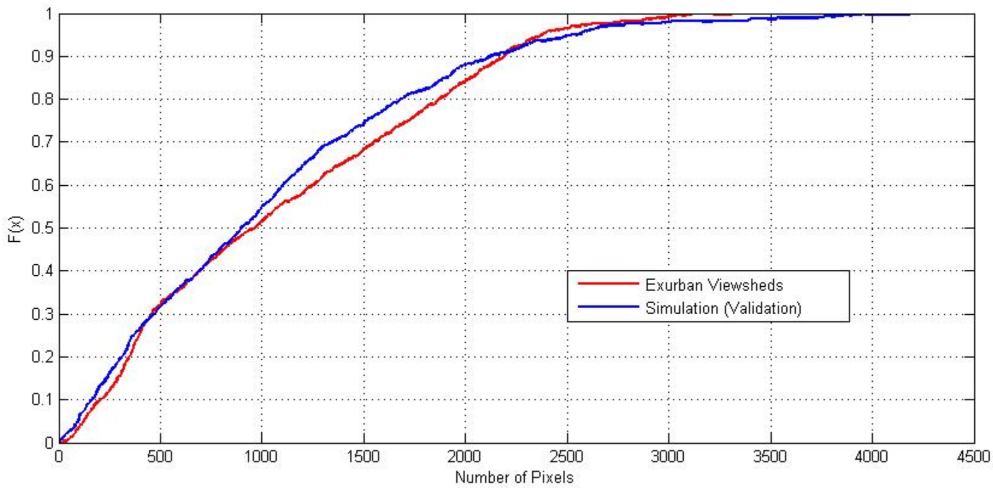
A two-sample Kolmogorov-Smirnov (K-S) test was used to compare the cumulative distribution functions (CDFs) for viewshed sizes of the actual exurban houses and the simulated houses (Figure 5). A p-value of 0.0105 indicates that the results are significantly different at the predetermined significance level of 0.05 (h = 1 if $p < 0.05$) (Table 3). The viewsheds of exurban homes are larger than would be expected if the houses were placed randomly and without consideration for viewshed size. The steep slope at the low values indicates that both the actual exurban and the simulated distributions display a positive (right) skew, where the mass of the distribution is concentrated on the left and there are relatively few high values.

Table 3. Comparison of the actual exurban house distribution to the simulated distribution for each visual quality metric: greenness, viewshed size, and ruggedness (Two-sample K-S test).

Comparison between Actual Exurban Distribution and Simulated Distribution	h [a]	*p*-Value	k [b]
Mean NDVI Value	1	<0.0001	0.1152
Size	1	0.0105	0.0721
Total (Mean) TRI Value	1	<0.0001	0.1112
Maximum TRI Value	1	<0.0001	0.2565

[a] The result h is 1 if the two data sets are from different distributions at the 5% significance level. [b] The test statistic k is the maximum difference between the curves.

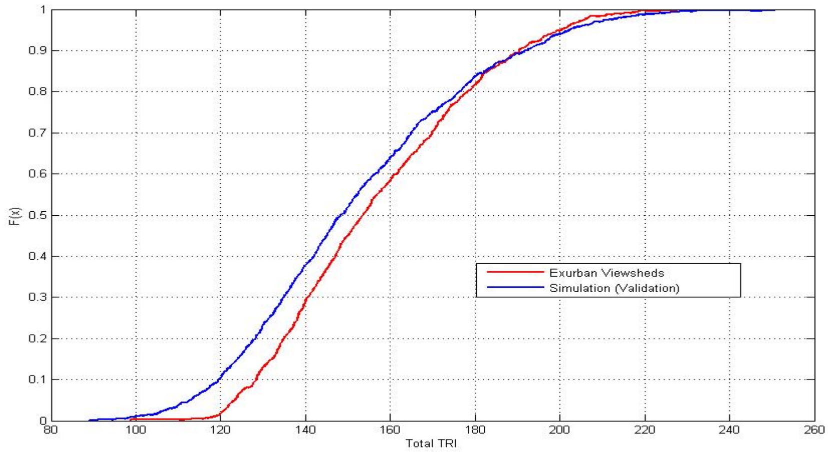
Figure 5. Cumulative distribution functions of viewshed size for actual exurban and simulated (validation) houses.



3.1.3. Terrain Ruggedness

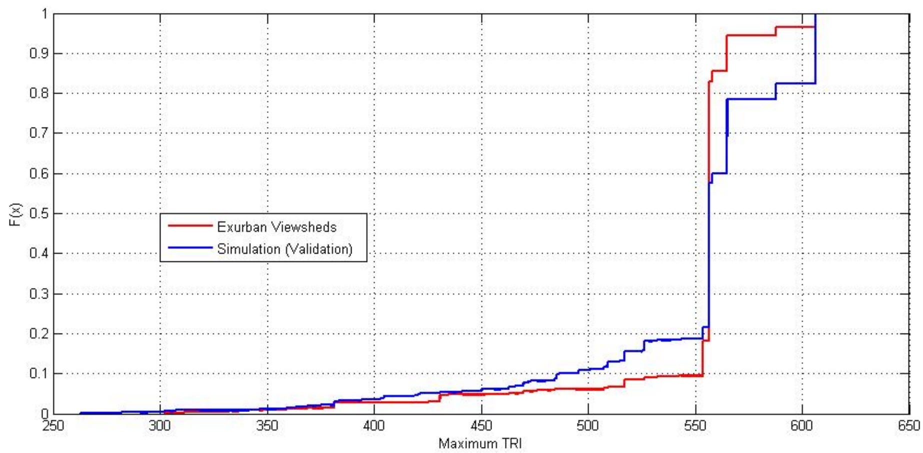
We performed a two-sample Kolmogorov-Smirnov (K-S) test to compare the cumulative distribution functions (CDFs) for total (mean) Terrain Ruggedness Index (TRI) of the actual exurban houses and the simulated houses (Figure 6). The exurban houses have viewsheds with higher total TRI values than do the simulated (validation) houses. A *p*-value < 0.0001 indicates that the results are significantly different at the predetermined significance level of 0.05 (h = 1 if $p < 0.05$) (Table 3). The actual exurban households can see a significantly more rugged terrain than would be expected if the houses were placed randomly and without consideration for terrain ruggedness. The sigmoid shape of the curve indicates a normal distribution for both the actual exurban and simulated distributions.

Figure 6. Cumulative distribution functions of total (mean) TRI values for actual exurban and simulated (validation) houses.



A two-sample Kolmogorov-Smirnov (K-S) test was performed to compare the cumulative distribution functions (CDFs) for maximum TRI value of the actual exurban houses and the simulated houses (Figure 7). A p-value < 0.0001 indicates that the results are significantly different at the predetermined significance level of 0.05 (h = 1 if $p < 0.05$) (Table 3). The distribution functions cross at a TRI value of 556.4. At values below 556.4, the actual exurban houses have higher maximum TRI values than do the simulated distributions; this accounts for approximately 20% of the distribution. Almost two-thirds (64.6%) of the actual exurban viewsheds have a maximum TRI value of 556.4, while about one-third (36.0%) of simulated viewsheds have a maximum TRI value of 556.4. The highest 30% of maximum TRI values are significantly higher for the simulated viewsheds than for the actual exurban viewsheds.

Figure 7. Cumulative distribution functions of maximum TRI values for actual exurban and simulated (validation) houses.



3.2. Discussion

The specific elements of visual quality that attract amenity migration are poorly understood and the relative contributions of different elements to the appeal of an area are unclear. The objective of this paper was to explore the relationship between the location of exurban homes and aesthetic landscape preference, as exemplified through three visual quality concepts (naturalness, visual scale, and complexity) and represented by three corresponding metrics (greenness, viewshed size, and terrain ruggedness). We used viewshed-analysis to analyze these metrics for actual exurban houses and compared these distributions to a randomly-distributed simulated (validation) distribution. By looking at where people actually chose to build and live, it is possible to examine which drivers are optimized and which are compromised, and what aesthetic preferences drive house location selection in the Sonoita Plain.

We found that the actual exurban households can see significantly more vegetation than would be expected if the houses were placed randomly and without consideration for greenness. The actual exurban viewsheds had significantly higher average NDVI values than the simulated (validation) houses (p-value < 0.0001). Similarly, actual exurban viewsheds have significantly higher total (mean) Terrain Ruggedness Index (TRI) values than simulated houses (p-value < 0.0001). The exurban households see more-rugged or more-heterogeneous topography than would be expected if the houses were randomly placed. These two metrics are correlated as higher TRI values are found in the mountains that ring the Sonoita Plain and the mountains are also where we find oak and pine vegetation communities, which have higher NDVI values than the grasslands of the Sonoita Plain.

It is not clear which of these two metrics, greenness or terrain ruggedness, is the primary driver of aesthetic preference in this study area. In addition to mountains, the other landscape types that support a lot of woody vegetation and have higher NDVI values in southeastern Arizona are riparian areas [91]. The boom of residential development along riparian areas in Arizona [114] lends support to the importance of greenness in exurban house location selection, but terrain ruggedness is also important for landscape preference [36,72]. It could be that where there are trade-offs between greenness and ruggedness, we find different groups of amenity migrants. Birding enthusiasts, for example, may be drawn to areas that have more vegetation and can support a greater number and diversity of birds, such as riparian corridors, while avid hikers might be drawn to more mountainous terrain. Previous work in Québec, Canada found that new residential settlement patterns are significantly associated with specific landscape contexts [115,116]. Specifically, being urban, older and second-home owners were the most significant characteristics of residents associated with closed woodlot settings, for whom a preference for natural (or natural-looking) and pristine landscapes was an important consideration. This study also found a significant relationship between professional occupations (and therefore higher income categories) and residential settings located on upper hillsides, while part-time farmers were associated with lots on agricultural lowlands that are characterized by limited views [115]. This work suggested that specific landscape characteristics are a determining force shaping the social recomposition of rural communities [116]. Further study could help to tease apart these landscape preferences.

The step-wise maximum Terrain Ruggedness Index (TRI) value distributions of both the actual exurban and the simulated (validation) houses reflect the fact that there are a handful of high peaks that are visible from many parts of the central Plain. The distribution functions cross at a TRI value of 556.4. At values below 556.4, the exurban houses have a higher maximum TRI values than the simulated distributions. Almost two-thirds (64.6%) of the actual exurban viewsheds have a maximum TRI value of 556.4, while about one-third (36.0%) of simulated viewsheds have a maximum TRI value of 556.4. This value likely represents a single peak. The highest 30% of maximum TRI values are significantly higher for the simulated viewsheds than for the actual exurban viewsheds. The higher maximum TRI values for the simulated houses likely mean that they can see peaks in the Santa Rita Mountains to the northwest, which are the highest peaks in the region. Although significantly different, when we consider the range of potential TRI index values (0–4367), the difference between where the majority of values fall (556.4) and the highest maximum TRI value for the simulated distribution (606.3) is not very large.

It is interesting to note that the actual exurban viewsheds have a higher mean TRI value, but a lower maximum TRI value than the simulated (validation) viewsheds. The actual exurban homes see a more rugged terrain, but do not necessarily see the highest peaks. This provides some evidence that visual complexity throughout the viewshed may be more important than seeing the very highest peaks. It also suggests that the viewsheds with the highest peaks may not necessarily have the most visually complex views, which may be an important consideration when evaluating the desirability of a location.

Viewshed size measures the extent of the view, providing a method to compare visual scale and openness. Visual scale is related to the degree of openness in the landscape [42], which is directly related to landscape preference [66]. The viewsheds visible from the actual exurban houses were significantly larger than those visible from the simulated houses. The distributions of both the exurban and the simulated viewsheds are positively (right) skewed, where the mass of the distributions is concentrated on the left and there are relatively few high values. This may suggest that the number of very large viewsheds is limited. Exurbanites in the Sonoita Plain favor extensive views over the landscape and it appears that visual scale is important to the general aesthetic experience.

4. Conclusions

To date, most studies that have examined the spatial distribution of exurbanization in the context of amenity drivers have been at the county scale [2,17,36,79]. The findings of this study challenge the idea that regional landscape features are important independently of the particular setting of a housing unit [36,80] and call into question the use of county-level scales of analysis for the study of landscape preferences. The fact that there are differences in the visual-quality metric values between the actual exurban viewsheds and simulated viewsheds indicates that county-level comparisons may miss key landscape aesthetic drivers of preference. Although informative of broad trends, county-level scales of analysis may miss the specific features of a region that attract amenity migration. It is not just the general characteristics of the area that are important, but also the visual quality from each vantage point. County-level metrics may be especially problematic for counties in the Western US, which tend to be large and where aggregate measures may mean the loss of valuable information. The Sonoita Plain itself is a wealthy island of exurban development in a county where 24.5% of the population lives below the poverty line and the median household income in 2010 was $13,038 lower than for the state of Arizona (Table 1). County-level analysis of amenity-migration drivers would have missed this area entirely.

The three visual quality metrics evaluated here were selected because they were deemed important for this landscape, but they are by no means exhaustive and other visual quality metrics may be just as important in this and other similar landscapes. The concept of historicity, for example, may be especially relevant for areas of the American West where the ranching lifestyle has been idealized.

Cultural landscape elements, such as historical agricultural buildings, traditional agricultural structures, and historical roads can be important reminders of heritage in some landscapes and can provide residents with feelings of community integrity and richness. This historic continuity can give landscapes depth of meaning and a sense of time, thus enhancing landscape aesthetics [117–119]. Furthermore, some visual quality metrics may be more important than others, while other metrics may differ in importance depending on distance from the observer. Foreground vegetation, for example, has been found to be much more important than distant vegetation [120]. A weighted metric, such as a cost surface, could be used to place greater emphasis on the foreground and could help to further untangle aesthetic preferences. Visual elements interact to provide a comprehensive visual experience and it is likely that these landscape aesthetics, rather than one particular natural element [34], are key considerations in understanding exurbia. Which additional elements of the view contribute to aesthetic preference and to what extent are some of the questions that would benefit from further study.

Residents in very high amenity areas, displaying "last settler syndrome" and seeing further in-migration as a threat to the very landscape qualities that drew them initially, may adopt regulations to constrain further growth [4,21,36]. Housing prices are inordinately high in the most scenic rural counties and they no longer have the highest rates of migration [2]. This suggests that in rural areas that have long experienced amenity migration (US examples include Aspen, Sun Valley, Park City, and the Hamptons), further in-migration will increasingly be shaped by efforts to preserve valued landscape aesthetics rather than by the landscape preferences of potential new in-migrants. However, in areas that have more recently started to experience amenity migration, and where land availability and price still allow at least some choice, information about landscape drivers and exurban preference could prove helpful to planning and management efforts.

The economic shift from traditional resource industries to a New West economy based on a mix of the traditional industries and new sectors such as real estate and recreation [5,35] reflects not only changing economic forces, but also societal concerns about extractive uses in threatened landscapes. Many amenity-migrants view dispersed, low-density residential development as a conservation-compatible land use and certainly preferable to material production [20,121]. Despite this pervasive view, it has been argued that it is not material extraction/production but housing growth that poses the main threat to protected areas in the United States [122]. The spatial arrangement of exurban houses, roads and associated infrastructure will depend on the primary drivers of migration, and different spatial distributions will have different impacts on both social systems and ecosystem function. Information about landscape drivers may be of interest to local government officials, planners, and policy makers, as it may enable growth strategies designed to minimize negative ecological impacts on private and public lands. Beyond their value for conservation, strategies to protect visual quality may also be vital to sustaining economic growth in the New West.

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Author Contributions

J. Vukomanovic and B.J. Orr developed the approach and study design for this paper and interpreted the results. J. Vukomanovic performed the analysis and drafted the manuscript.

Conflicts of Interest

The authors declare no conflict of interest.

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