Landscape and Urban Planning 170 (2018) 177–186

Contents lists available at ScienceDirect

Landscape and Urban Planning

journal homepage: www.elsevier.com/locate/landurbplan

Research Paper

Recognizing the 'sparsely settled forest': Multi-decade socioecological change dynamics and community exemplars

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ARTICLE INFO

Keywords:
Land change
Coupled natural and human systems
Geographic classification
Exemplar Clustering Analysis (ECA)

ABSTRACT

Sparsely settled forests (SSF) are poorly studied, coupled natural and human systems involving rural communities in forest ecosystems that are neither largely uninhabited wildland nor forests on the edges of urban areas. We developed and applied a multidisciplinary approach to define, map, and examine changes in the spatial extent and structure of both the landscapes and human populations of SSF in the United States. We estimated that the SSF in the contiguous United States, which are home to only 6–7% of the population, account for over 60% of all forested land and over 30% of all land. From 1990 to 2010 SSF declined in area by 16%, changing little overall but declining markedly in proximity to urban perimeters. A PCA ordination and cluster analysis of the human and landscape characteristics of SSF areas revealed complex and regionally variable patterns. Very broadly, SSF in the far northern and western states are less densely settled and more amenity driven, while the southeastern states north through Pennsylvania and Ohio are more densely settled and more agricultural. The socioeconomic characteristics of SSF are often quite variable at fine scales, especially in proximity to urban areas. Our improved multidisciplinary understanding of SSF raises important questions about regional differences in the dynamics, structure and future socioeconomic trajectories of these forests. To best manage these landscapes for the sake of both human and natural systems, SSF need to be considered a distinct land classification in their own right, not merely perceived as fuzzy boundaries around wild lands or urban areas.

1. Introduction

Over the last century, most North American forests have undergone major transitions, starting with timber extraction and clearing of wild forests for farmland, and followed by reforestation of marginal lands (Morzillo et al., 2015; Ramankutty & Foley, 1999). Significant population shifts coincided with these historical dynamics, reflecting changes in response to economic activity and livelihood opportunities (Kauppi et al., 2006; Mather, Hill, & Nijnik, 2006; Munroe, van Berkel, Verburg, & Olson, 2013). Compared to peak populations in forested landscapes over the last 100 years, current forests are generally sparsely settled (US Census Bureau, 2014), but in some places resident populations are increasing due to amenity demands for recreation and tourism (Drummond & Loveland, 2010; McCarthy, 2006) as well as in-migration. These 'sparsely settled forests' (hereafter SSF) are often in transition with communities and people struggling to adapt to changing circumstances without losing their fundamentally rural identity (Morzillo et al., 2015). Despite the cultural and ecological significance

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http://dx.doi.org/10.1016/j.landurbplan.2017.10.009
Received 22 July 2016; Received in revised form 9 June 2017; Accepted 28 October 2017
Available online 02 November 2017

of these forested rural landscapes and their vulnerability to internal and external pressures, both in North America as well as globally (Ellis et al., 2013), SSF have neither been rigorously defined nor received the study they deserve.

To date, both in the US and globally, research on changing land use has focused on discrete and widely accepted land classifications such as urban, agriculture, wildlands etc. (Ellis et al., 2013; Verburg, Berkel, Doorn, Eupen, & Heiligenberg, 2009) that do not explicitly consider population density and often implicitly assume settlement patterns (Fleishman et al., 2011). Historically, for example, ecologists have tended to study either remnant wildlands and protected areas with minimal human presence (Martin, Blossey, & Ellis, 2012) or intensively managed street trees and parks that represent a relatively small fraction of the urban landscape (Ahern, 2013). Social scientists seem more cognizant of the importance of studying the entire gradient of human settlement (Brown, Johnson, Loveland, & Theobald, 2010; Darling, 2005; Irwin & Bockstael, 2007; Radeloff et al., 2010; Stein et al., 2005), but often restrict their analyses to specific regions (e.g., Southeast or Pacific Northwest) or land use systems (e.g., forest or agricultural lands) missing broader scale processes and interactions.

Recently, however, increasing interest in forested landscapes as socioecological systems has triggered interdisciplinary efforts examining situations where issues arise when forests, housing, and human populations converge. For example, the US Forest Service's Forests on the Edge (FOTE) program (Smail, 2010; Stein et al., 2005; White & Mazza, 2008) and the Wildland-Urban Interface (WUI) research programs (Martinuzzi et al., 2015; Radeloff, Hammer, & Stewart, 2005) investigate development pressure and wildfire risk, highlighting the spatial patterns of forest risks. Increasing attention also has been placed on forest as important sources of ecosystem services (Nelson et al., 2009; Stein et al., 2005). These efforts have improved understanding of forests in which people live, but have not fully investigated the diverse social characteristics and economic conditions that characterize SSF. Even though SSF are situated in the middle ground between the matrix of lands that constitute urban, suburban and exurban settlements (hereafter "(ex)urban") and truly "wholly unsettled, wild nature" (hereafter wildlands), they have traditionally been classified simply as rural despite experiencing specific land change dynamics and population pressures different from traditional land use classes. We argue that SSF require more specific study and attention given their unique challenges and the extensive range and the importance of ecosystem services that they provide.

Popular narratives seem to suggest that SSF will ultimately disappear due to urbanization and abandonment of remote areas. News coverage has, for instance, suggested that "Rural areas dwindle as residents flock to cities", often accompanied by notions of economic downturn and the development of ghost-towns (Halladay, 2001; Shah, 2014). Yet, there have been no systematic investigations of this narrative of collapse. Decennial Census data in fact show that population in SSF have been relatively stable over time, even in the face of shocks and collapse of resource bases due to local exhaustion of natural resources (Morzillo et al., 2015). However, rural areas have also experienced periods of increasing (e.g. 1970–1975) (Beale, 1977) and decreasing (e.g. 2010–2014) population (US Census Bureau, 2014), in addition to periods of temporal variability within SSF. Unfortunately, a national-scale assessment of population trends in forested rural (SSF) lands, to the best of our knowledge, is lacking, as is any analysis of the socio-economic structure of SSF communities. There are good reasons to advance such studies.

Maintaining SSF is likely to conserve important ecosystem services that are broadly beneficial. SSF represent historically significant and aesthetically pleasing landscapes prominent in fine art that for many are associated with a 'sense of place' (e.g. Hudson River School of painting, works of literature by Faulkner, James Fenimore Cooper, and Laura Ingalls Wilder) and numerous example of SSF with high cultural capital are prominent globally (Oteros-Rozas, Martín-López, Fagerholm, Bieling, & Plieninger, 2017; Pastur, Peri, Lencinas, García-Llorente, & Martín-López, 2016). This iconic standing has made these SSF prized for leisure and recreation, as well as, inspiration. Ecologically, a substantial fraction of ecosystem services consumed in urban areas are derived from SSF (MA, 2005; Colgan, Hunter, McGill, & Weiskittel, 2014). Forests also provide fiber, regulate atmospheric systems, and offer invaluable sources of clean water (e.g. Koeppel, 2001), and SSF are a major resource in the conservation of forest plant and animal species (Colgan et al., 2014). The cultural and ecosystem services provided by SSF benefit those who reside in them, as well as populations who live in urban, suburban and exurban areas.

Moreover, a better understanding the nature of SSF can add insight into the complementarity of natural and human systems (An & López-Carr, 2012; Liu et al., 2007). Forest residents depend on ecological processes to provide resources for extraction including timber and pulp, and the maintenance of the natural landscape for amenity-based tourism (Deller, Tsai, Marcouiller, & English, 2001; Wu & Gopinath, 2008). Reciprocally, ecological systems can be enhanced through control of diseases and pests (Moser et al., 2009) and via management through fire that improve forest health in some systems (Naveh, 1994). Examining SSF as coupled systems provides a novel opportunity to understand the dynamics and structure of forest systems in the broader context of system resilience and vulnerability.

To advance and encourage the study of SSF, we present a national-scale assessment of population trends for SSF lands in the contiguous United States and an initial interregional evaluation of the socio-economic structure of SSF communities. By evaluating the 1) the extent; 2) the change over time and; 3) the socio-environmental heterogeneity of SSF, we provide an overview and summary of the future of this culturally and ecologically important component of the North American landscape.

2. Material & methods

2.1. Overview

We started our investigation by characterizing, defining and mapping SSF. While numerous tangential studies examining forests and rural areas have partially captured SSF, this is the first study that specifically addresses the geographical extent of forests where people live and work. To capture the dynamics of SSF, we analyzed longitudinal land cover, population and housing unit density across two decades (Tables 1 and 2: 1990, 2000 and 2010). We also collected complementary socioeconomic variables, obtained for the year 2000, to evaluate variation in the factors that shape SSF. All data were resampled to 10 km resolution, which has been useful for assessing land use patterns in the conterminous United States in previous studies (e.g. Lawler et al., 2014)

2.2. Background

Patterns and trends in SSF reflect changes in human settlement and local and global economies. The amount of land that can be considered SSF is determined by migration of people into and out of those landscapes and the resulting changes in the ecological conditions. Maintaining a sparse but stable human population while retaining the significant forest cover in which these rural communities are embedded is challenging. On the one hand, in-migration to take advantage of natural amenities can irrevocably change and destabilize the character and function of SSF (Morzillo et al., 2015; Van Berkel, Munroe, & Gallemore, 2014; Verburg et al., 2009). Increased settlement density near public forest lands (Radeloff et al., 2010; Stein et al., 2005) and at the edge of urban areas (Miller, 2012; Radeloff et al., 2005) can disrupt ecological systems. FOTE research predicted that by 2030 approximately 11% of the privately held forest land in the US will have been subject to intensive housing development, although with

Table 1
Data used for the classification of SSF with a spatial resolution of 10 km. Dates are approximate because of variability in data availability, which meant not all layers were from these exact three years.

Variable	Description	Source
Housing units	Each census block was divided into privately owned and publicly owned lands using the Protected Areas Database (PAD-US; CBI Edition) population and housing numbers were assigned to the privately-owned portion of each census block (Martinuzzi et al., 2015) and to each pixel proportionally.	US Census Bureau, (1990, 2000b, 2010)
Forest cover	NLCD classes 41, 42, 43 and 90 for NLCD 2001 and 2006; classes 41, 42, 43 and 91 for NCLD 1992 were aggregated and used to calculate percentage forest cover for each 10-km pixel. Because NLCD survey years were not aligned with US Census years, we used US Census years, we used 1992 for 1990, 2001 for 2000 and 2006 for 2010.We aggregated the data to the Anderson Level I class (i.e. "forest") to minimizes the potential differences among NLCD datasets (see Fry et al., 2012).	Fry et al. (2012); Homer et al. (2007); Vogelmann et al. (2001)

substantial regional variation (White & Mazza, 2008). Housing development in sparsely settled forests near either public forest lands or urban centers is not necessarily a new trend though, and has increased steadily, for example, in northern Wisconsin since 1940 (Gonzalez-Abraham et al., 2007). Conversely, some SSF lands are losing population through outmigration to urbanized areas resulting in disruptions to the social structure of these communities and loss of unique managed landscapes (Kauppi et al., 2006; Mather et al., 2006; Munroe et al., 2013). While this outmigration is partly driven by a consistent trend of rural to urban migration across the US, the loss of the economic base in many rural communities has also caused declining populations in these forest landscapes. Prime examples include loss of central economic engines such as mills or timbering jobs in places like Millinocket, ME and Sweet Home, OR (Morzillo et al., 2015). Subsequent changes in forest cover and composition due to reduced harvest have pushed once SSF to wild areas, and some forests have regrown on former agricultural lands.

2.3. Quantitative definition of SSF

As no clear geographic definition of what constitutes a SSF exists for the US, we consulted with forest policy experts and forest management practitioners to help formulate a classification. These consultations involved visual comparisons of different mapped extents of SSF based on varying percentages of forestland and housing densities. Percent forest cover per 10 km pixels was developed using the National Land Cover Data product (NLCD). To combine NLCD data with housing information, we employed US Census data (block level), calculating the number of housing units (HU) by pixel. The authors on this paper, all with long term research programs in Arkansas, Connecticut, Maine, Ohio, Oregon, North Carolina and Wisconsin, along with forest policy experts and practitioners evaluated the spatial configurations of these maps seeking

Table 2
Socio-economic variables and data sources used to explore the socio-environmental variability within SSF. Variables are listed in terms of their importance in defining the clusters within the exemplar analysis as determined by a post-hoc regression. Correlations among variables are provided in Fig. A.3 .

Variable	Description	Source
Percentage agricultural land	Percentage NLCD classification of agricultural (classes 81 & 82) lands per 10-km pixel	Homer et al. (2007)
Percentage of jobs in farming	NAICS data on percentage of individuals employed in the farming sector compared to total employment. Mapped using census block data scaled to 10-km pixel	US Census Bureau, (2000a)
Travel time in seconds to a city > 100,000 residents	Shortest network path based on actual speed limits of the road network. This equate to approximate drive time to the nearest urban center with great than 100,000 residents	US Census TIGER products (2000)
Percentage of population with a bachelor's degree	Census block data scaled to 10-km pixel	SEDAC and US census Bureau (2000)
Percentage forest cover	Percentage NLCD classification of forest lands (classes 41, 42, 43 & 90) per 10-km pixel	Homer et al. (2007)
Change in forest cover	Difference between forest from 1990 to 2010	Fry et al. (2012); Vogelmann et al. (2001)
Percentage of jobs in service	NAICS data on percentage of individuals employed in the retail trade sector compared to total employment. Mapped using census block data scaled to 10-km pixel	US Census Bureau (2000a)
Percentage of land publicly owned	Percentage of public land in each 10-km pixel	USGS (2010)
Percentage of jobs in finance (including real estate and banking)	NAICS data on percentage of individuals employed in the financial and insurance and real estate (FIRE) sectors compared to total employment. mapped using census block data scaled to 10-km pixel	US Census Bureau (2000a)
Population size in 2000	Real population for 2000	US Census Bureau (2000b)
Percentage of jobs in manufacturing	NAICS data on percentage of individuals employed in the manufacturing sector compared to total employment. mapped using census block data scaled to 10-km pixel	US Census Bureau (2000b)
Percentage urban land	Percentage NLCD classification of urban lands (classes 21, 22, 23 & 23) per 10-km pixel	Homer et al. (2007)
Percentage of jobs in agriculture and forestry support.	NAICS data on percentage of individuals employed in the agriculture and forestry support sector compared to total employment. mapped using census block data scaled to 10-km	US Census Bureau (2000b)
Percentage of houses defined as seasonal	Census block data scaled to 10-km pixel of homes inhabited seasonally	SEDAC and US census Bureau (2000)
Percentage of population below poverty line	Census block data scaled to 10-km pixel	SEDAC and US census Bureau (2000)
Mean age of houses in years	Average home age. Ppre-1950 houses were assumed an average age of 75 years, 1950–1969 houses were assumed an average of 40 years in 2000, etc	SEDAC and US census Bureau (2000)
Population growth 1990–2010 (no. individuals)	Difference between population from 1990 to 2010	US Census Bureau (1990, 2010)
Percentage of population aged over 65	Census block data scaled to 10-km pixel	SEDAC and US census Bureau (2000)
Percentage of population aged under 25	Census block data scaled to 10-km pixel	SEDAC and US census Bureau (2000)
Percentage of jobs in mining	NAICS data on percentage of individuals employed in the farming sector compared to total employment. mapped using census block data scaled to 10-km pixel	US Census Bureau (2000b)

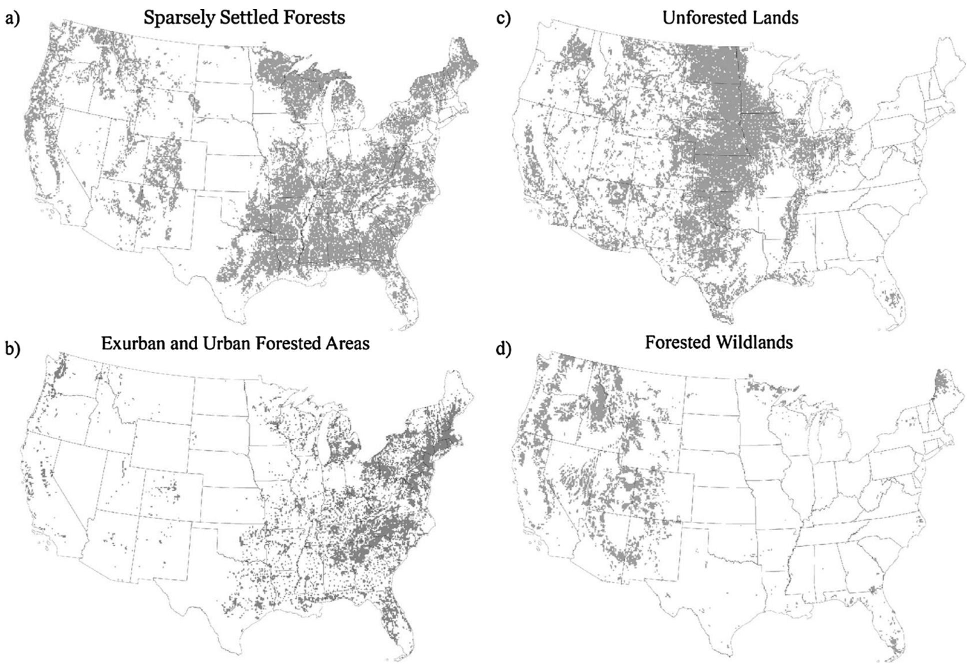

Fig. 1. a) Sparsely settled forests (≥20% forest, 0.1 ≤ HU/km^2 < 10); b) (ex)urban forested areas (≥20% forest, HU/km^2 < 10); c) nonforested lands (< 20% forest cover); and d) forested wildlands (≥20% forest, < 0.1 HU/km^2) for the year 2000.

a good match to local understanding of SSF. Discussions of fine-grained patterns were held for each region assessing whether derived maps corresponded with our emergent understanding of SSF.

Forested land covering more than 20% of a 10-km pixel with housing densities from 0.1 HU/km^2 to 10 HU/km^2 (Fig. 1a) was agreed to constitute what could best be described as SSF. This quantitative definition includes more housing units than common definitions used in other examinations of the urban-rural/wildland divide (6.17–6.18 HU/km^2 compared to 10 HU/km^2: Table A1 Supplementary material) in order to capture our targeted inhabited forests. To help frame a discussion of SSF, we also defined and considered the extent of wooded landscapes that are not considered sparsely populated including, urban, suburban and exurban forested areas with at least 20% forest cover but housing densities greater than or equal to 10 HU/km^2 (Fig. 1b); unforested lands (i.e. forest cover less than 20%) (Fig. 1c); and forested wildlands with forest cover greater than 20% and housing densities less than 0.1 HU/km^2 (Fig. 1d). The patterns of these four landscape types was stable at lower housing density (0.1 HU\km^2) and forest thresholds (≥20% forest cover) but sensitive to the upper threshold for housing density (10 HU/km^2). Our upper threshold ultimately determines where exurban land use gives way to the rural, a fuzzy boundary that we address further in the discussion.

2.4. Assessment of changes

To investigate the dynamics of SSF over time, we mapped SSF in 1990, 2000, and 2010. Pixels that transitioned from SSF to non-SSF or *vice versa* were also mapped to identify the spatial structure of changes within these landscapes. We then compared these transitions with change in population density assuming housing density is related to population change. Wildlands, (ex)urban and nonforested areas were also examined for the reference years to visualize transitions occurring between these landscapes and SSF.

2.5. Analysis of socioeconomic variation within SSF

To assess socioeconomic heterogeneity within SSF, we applied two multivariate techniques to extract and summarize similarities within and differences among regions in SSF based on key social and economic variables (Table 2). First, we conducted a principal component analysis (PCA) with a varimax rotation, and mapped and plotted PC loadings to identify strong correlation among variables (Fig. 4). Second, we used a novel exemplar clustering analysis (ECA) (Cardille & Lambois, 2009) of the same data, to identify and locate discrete socioeconomic subcategories of SSF. While the PCA describes the relative influence of the explanatory socioeconomic variables explored, we also found it useful to determine exemplar pixels via ECA to more closely evaluate members of the input data set that are representative of each specific cluster. The exemplar clustering analysis uses the affinity propagation algorithm (Frey & Dueck, 2007) that has an advantage in speed, general applicability, and good performance over *k*-means and Markov clustering (Frey & Dueck, 2007; Vlasblom & Wodak, 2009). Affinity propagation is based on a similarity matrix for the data points and uses an iterative process to identify a quality set of discrete clusters and corresponding exemplars – i.e., individual pixels that provide a good representation of the other pixels classified into the same cluster. We standardized the socioeconomic variables with the z-score transformation prior to computing similarity among the SSF pixels using negative Euclidean distance. To determine an interpretable number of subcategories within SSF, we set the preference parameter of the affinity propagation algorithm to ten times the minimum negative Euclidean distance (Frey & Dueck, 2007). The affinity propagation algorithm was implemented with the apcluster package (Bodenhofer, Kothmeier, & Hochreiter, 2011) in R, v2.15 (R Core Team, 2013).

Twenty socioeconomic variables were included in the final analysis (Table 2). We included the percentage cover of land cover types that influence the economic base of these landscapes. To capture housing stocks, poverty, education levels and demographic composition we included SEDAC (Socioeconomic Data and Applications Center) US 2000 Census data. Such socioeconomic factors often structure how regions experience social transitions and the resulting economic growth potential (Munroe et al., 2013). We included percentage seasonal housing and percentage of public lands to address the trend of forest areas being increasingly settled and used as second homes because of their recreational and leisure amenities (Van Berkel et al., 2014). Amenity migration into SSF is both an opportunity for economic resurgence and a potential threat to the long-term sustainability of these systems. Amenity development can result in shifts in social cohesion as demographics change, and can introduce new ecological threats as housing construction and recreation increase. Ultimately, increased settlement and development of SSF can result in a transition to high density (ex) urban regions and/or changes in the ecological conditions of SSF. We used the North American Industry Classification System (NAICS) to quantify the percentage of employment across the diverse employment sectors within SSF including production dominated industries (mining, forestry), service and leisure (amenity), manufacturing, and finance and high-tech (Morzillo et al., 2015). Manufacturing and extraction based on natural resources is often associated with short-term and low skilled employment due to volatile global commodity markets and variability in stocks of natural resources (i.e., timber, coal). Amenity jobs are also often low-skill, low-income, and dependent on tourist demand (Saint Onge, Hunter, & Boardman, 2007), while finance and high-tech typically have higher pay and are not affected by natural resource commodity markets. We calculated travel time to the nearest urban service center with at least 100,000 inhabitants using transportation network data (US Census TIGER products, 2000) including speed limits. Travel time to urban centers influences SSF by increasing the access of rural dwellers to markets and services, and increasing the access of urban dwellers to rural areas (Olson & Munroe, 2012).

3. Results

3.1. Extent of SSF

In 1990, SSF covered 2,408,900 km^2 of the contiguous US land area (30.1%), was home to 16,628,000 people (6.7% of the population), and had 7.48 million houses (7.4% of the total housing stock). SSF comprised 60.1% of forestlands in the contiguous US. The remaining forest was either wild (17%) or more densely settled (ex)urban lands (22%).

3.2. Historical changes in extent of SSF

The ebb and flow of lands out of and into SSF is a defining feature of SSF. Approximately 16.3% of the land in SSF in 1990 was no longer SSF by 2010. Conversely, 2.1% of land not previously considered SSF in 1990 or 2000 became SSF by 2010. This resulted in a net 9.5% decline in area of SSF in just 20 years (Fig. 2). Similarly, the number of people living in SSF declined over the same period (16.6 million to 14.7 million), as did housing stock (7.5 million housing units to 7.4 million housing units). The decline in the total area of SSF was primarily due to SSF converting to (ex)urban lands. Housing density within SSF increased (from 3.11 HU/km^2 in 1990–3.38 HU/km^2 in 2010), but population density showed a more complex pattern, increasing from 6.9 people/km^2 in 1990–7.1 people/km^2 in 2000, then declining to 6.7 people/km^2 in 2010.

There were a variety of causes for the decline of SSF over the period (1990–2010) (Fig. 2, Table A2: Supplemental material). A significant portion, 26%, (4.2% of the decline) was the result of loss of forest cover, another 2.9% (18% of the decline) was due to housing decreases, and 9.2% of the land (57% of the decline) became SSF because of housing increases. New SSF resulted from reforestation in the case of 3.7% of SSF land area (50% of the increase), population declines (0.3% of the land, 1.6% of the increase) or increasing population (3.7% of the land, 49% of the increase) in former wildlands. Population declines in the face of increased housing construction suggest broader community shifts in SSF likely related to fewer people per housing unit (White, Morzillo, & Alig, 2009) and increased ownership of second homes in some locations (Van Berkel et al., 2014).

Maps of SSF illustrate the spatial structure of the area transitioning into and out of SSF (Fig. 3). SSF transition at the edges of (ex)urban areas and at the edges of wildlands due to increases and decreases in housing density, respectively. Forest cover change explains most of the remaining transition, while populations migrating to wildlands with subsequent housing change also account for a part of all SSF gains. Specifically, the pixels transitioning into SSF (Fig. 3a) are primarily wildlands in the west (entering SSF due to increasing population), or ecotones within originally sparse tree cover that is becoming more forested along the edge of the Great Plains. Most losses of SSF classification are in the east and trace to housing density reaching (ex)urban levels (Fig. 3b), especially around urban centers (Fig. 1b). In the west, decreasing housing density resulted in increases of wildlands in remote and often mountainous areas (Fig. 3b).

3.3. Socioenvironmental variation within SSF

Multivariate analyses applied to socioeconomic data showed substantial heterogeneity within SSF for the year 2000 (Table 2) despite similar population density and land cover characteristics imposed by our operational definition of SSF. The horizontal axis (PC1: explaining 18.2% of variance) captures an 'urban-wildland' gradient (Fig. 4a, c). At one extreme are regions with relatively high population density and percentages of urban and agricultural lands in the southeast north, portions of the Midwest, and a pocket in the coastal west (Fig. 4a, c: purple). At the other extreme are regions in the Intermountain West and the far north of the east and Midwest with long travel times to large urban centers, a high percentage of seasonal homes, and a high concentration of public land (Fig. 4a, c: green). The vertical axis (PC2: explaining 11.3% of variance) represents near-city, amenity-based

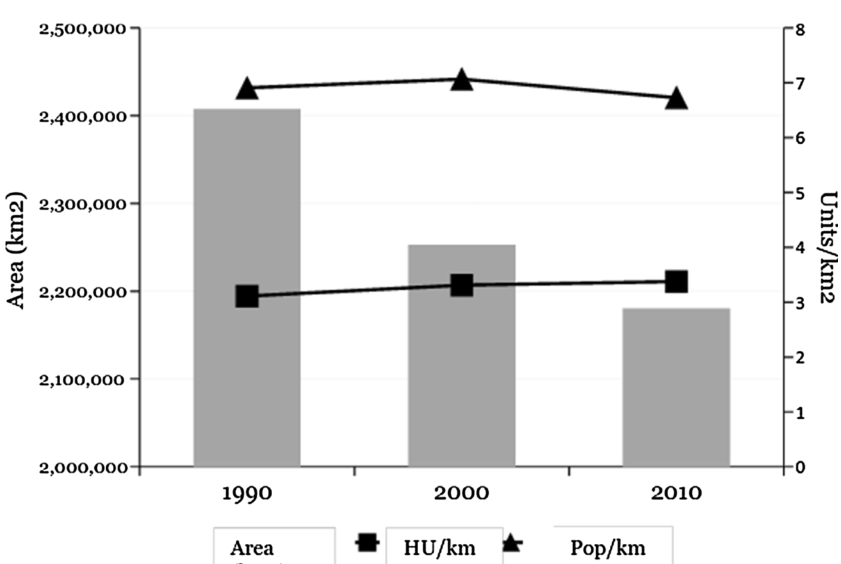

Fig. 2. Changes in SSF from 1990 to 2010–Gray bars show the decline in total land area classified as SSF from 1990 to 2010. Housing density and population density remained relatively constant, indicating that declines in total housing and total population within SSF were largely due to the decrease in the area of SSF.

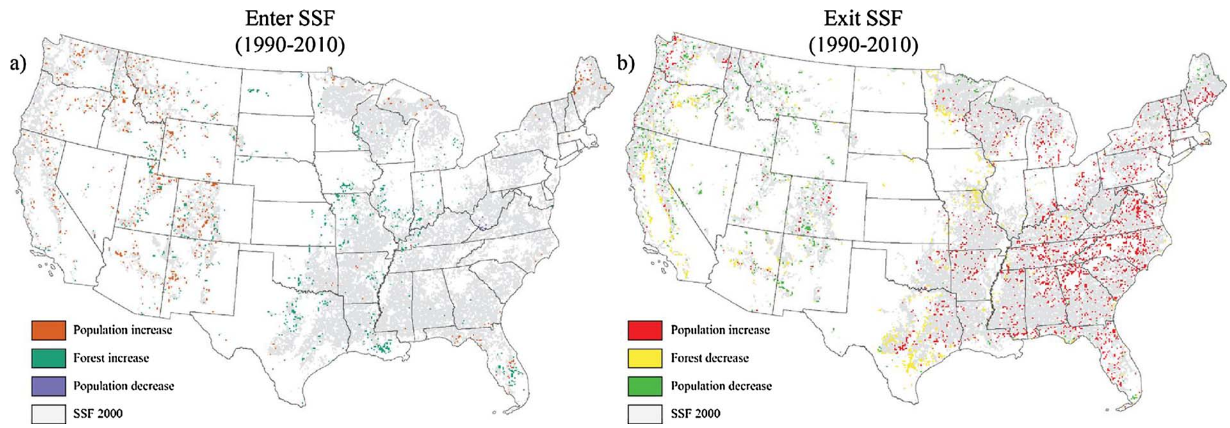

Fig. 3. a) Lands that were not SSF in 1990 but become so in 2010, and b) lands that were SSF in 1990 but not in 2010, with colors indicating the reasons for change.

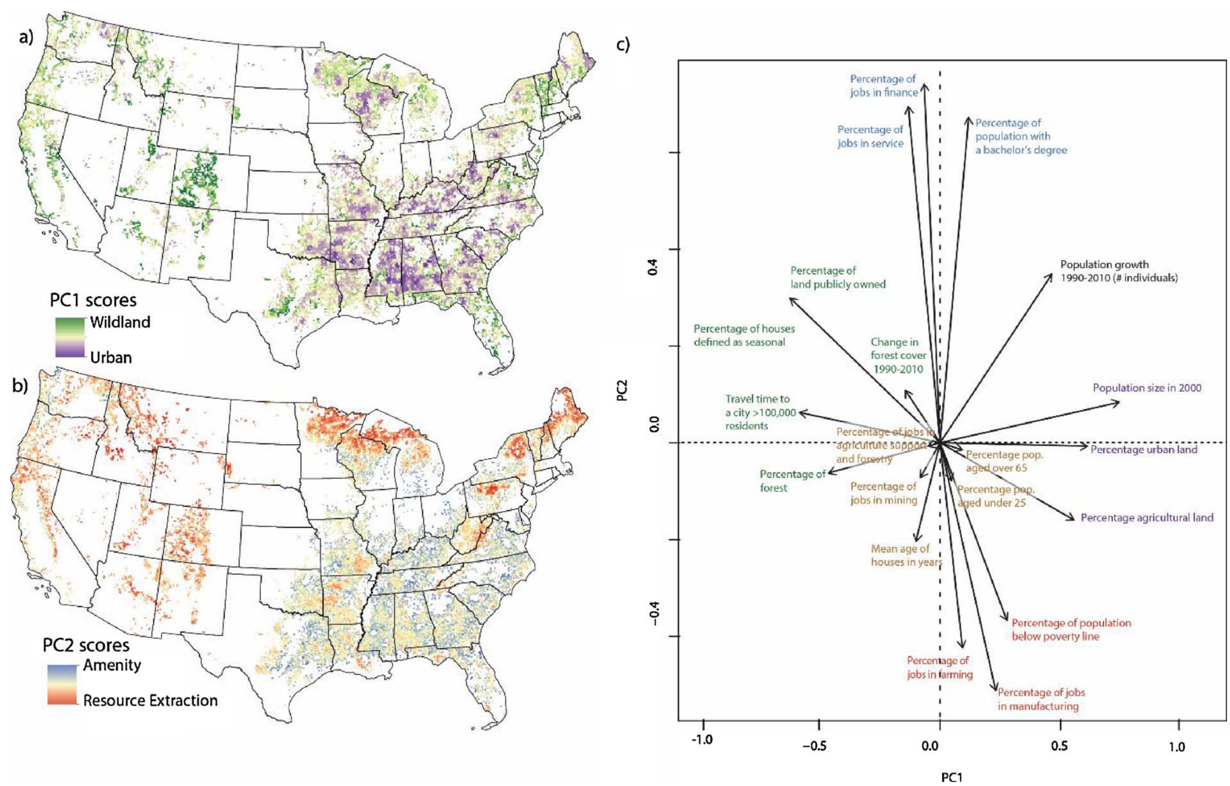

Fig. 4. Maps of component scores for a) PC1: Urban/Wildland; and b) PC2: Amenity/Resource Extraction; and c) biplot of loadings of 20 socio-economic variables on the first two principal component axes from rotated principal component analysis of pixels within SSF(2000). PC loadings (c) correspond to the identified map gradients i.e. urban: purple; wildlands: green; amenity: red; resource extraction: blue; and limited discriminatory power in brown.(For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

economies with high percentages of service- and financial-sector jobs and where residents typically have baccalaureate level education (Fig. 4b, c: red). Extraction-based economies, as well as more farming and manufacturing jobs, and higher poverty rates are found farther from cities (Fig. 4: blue), although this pattern is reversed in the upper Great Lakes. Population growth loaded heavily on both axes, falling between urban and amenity-economy dominated areas (Fig. 4c: black), while several socioeconomic factors had little discriminatory power (Fig. 4c: brown).

Our exemplar analysis identified eight clusters within SSF (Fig. 5, Table 3) when the preference parameter within the affinity propagation algorithm was set to ten times the minimum similarity. We chose a low preference value to ensure an interpretable set of clusters because of the high socioeconomic heterogeneity within SSF. Without the preference parameter, the algorithm identified 1013 clusters. One consequence of restricting our analysis to a reduced set of clusters is that the range of values for socioeconomic variables found in each cluster overlapped considerably (Fig. A2 in Supplimentary file). However, mapping the clusters helps to characterize important factors shaping SSF (Table 3) and for contextualizing specific local challenges (Fig. 5).

We identified two highly distinctive clusters in the initial assessment: agriculture and mining SSF versus other SSF. Agricultural and mining SSF are separated from other SSF by either the high percentage of land in agricultural or employment dependence on mining jobs, respectively (Supplemental Fig. A2). The agricultural group is located on the edges of the midcontinental “Breadbasket” region in areas that were originally forested (Fig. 5). Mining is located primarily in Appalachian coal regions and in Wyoming, Texas, Oklahoma and Georgia.

There was good correspondence between the PCA and exemplar clustering analyses. The Sparse/Populated gradient is strongly

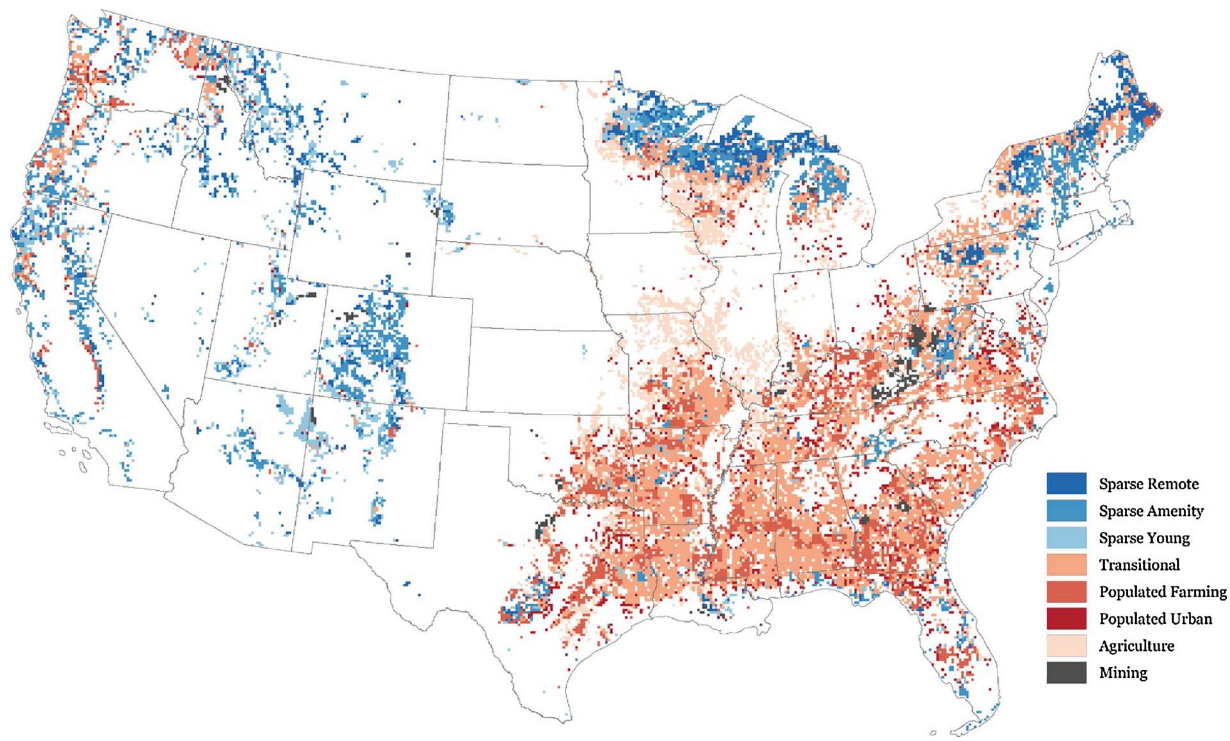

Fig. 5. Socioeconomic variation within SSF for the year 2000.

reminiscent of PCA axis two characterizing the urban-wildland gradient. Amenities versus extraction economies are reflected within the Sparse subgroup of pixels and again within the Populated subgroup of pixels with similar spatial configurations (Figs. 4 and 5). However, the exemplar cluster method distinctly identified the mining and agriculture categories and the Sparse Young category as well as highlighting variability within regions.

4. Discussion

We found that Sparsely Settled Forests represent a large fraction of land in the contiguous United States – over 60% of forested land and over 30% of all land – and is home to 6–7% of the US population. Over time, SSF has remained fairly stable in total area, but shifted at the margins, expanding and contracting around urban and wildland landscapes. Within SSF, we found substantial socioeconomic variation, often at small spatial scales i.e., neighboring 10-km pixels. However, we also identified some broad patterns, which were consistent when we analyzed SSF with two very distinct multivariate methods. There are clear regional differences in housing density with the northern and western portions of SSF being less and the southeast being more densely housed. Second, there is large variation in terms of employment, especially between amenity and extraction-based sectors, which depend largely on proximity to cities, and in a few cases large-scale agriculture or mining industries. Economic growth also likely relates to a high proportion of young people. However, these gradients capture only a small fraction of the variance (31%) and highlight the diversity within SSF.

4.1. Details of interpretation

Before turning to discussing implications of our findings, we address several cautionary points that arise in interpreting our results. First, we have defined SSF based on housing density and forest cover. In

Table 3
Summary interpretation of the exemplar cluster analysis. There are 8 clusters identified. The distribution of 20 socioeconomic variables for each cluster is shown in supplemental Fig. 3. The geographic spread of the 8 cluster types is shown in Fig. 5. *Sparsely settled is interpreted based on population density but also proximity to cities, amount of vacation homes and amount of public lands (top row of supplemental Fig. S3). Populated is the opposite. Transitional is intermediate.

Cluster Name	Indicator Variables	Geography
Sparse & Remote	Sparsely settled* (indeed most sparse on several measures) and fewer residents with baccalaureate degrees, fewer service and finance jobs	Primarily New England, upper Great Lakes and Intermountain West – often buffered from cities by the Sparse Amenity cluster
Sparse Amenity	Sparsely settled* and more baccalaureate degrees, and more service and finance jobs than “Sparse & Remote”	Also concentrated in New England, Great Lakes and Intermountain West but often closer to cities
Sparse Young	Sparsely settled*, not distinct from the average sparsely settled location except it has more under 25 years of age and fewer over 65 years of age than any other cluster	Almost entirely Intermountain West with a cluster in Minnesota.
Agricultural	Heavily farmed lands. Average in most other respects	Edges of the “Breadbasket” – roughly the forest to prairie transition
Mining	Much higher proportion of jobs in mining. Otherwise typical.	Appalachia and a few outposts in Texas, Oklahoma, Wyoming and Georgia
Transitional	Intermediate on the sparse/populated scale* Very typical/average of SSF in all other regards	Well scattered across the contiguous US although most common in the southeastern US
Populated Farming	Populated*. More jobs in farming and forestry/agriculture than the Populated Urban	Predominate in the southeastern US but scattered throughout the US
Populated Urban	Populated* Less farming and more rapidly growing populations than Populated Farming	Predominate in the southeastern US but scattered throughout the US (near cities in other regions)

principle, it would be desirable to assess "where people work" as an ancillary criterion to where they live to characterize urban versus rural landscapes. Commuting from SSF to employment centers is likely a strategy used by residents of SSF (Olson & Munroe, 2012). We explored defining SSF based on both housing density and employment, but available employment data made this classification approach problematic. Our inclusion of employment data partially captures regional employment while our cost distance measure may indicate a propensity for commuting. However, we do not fully capture where people work with these indicators.

Second, we would have also liked to include a measure of industrial forests, which are prevalent in the south of the US, to control for temporary forest cover loss due to harvesting. Such resource extraction represents a distinctive SSF land system. These temporary losses of forest cover may have reduced the area of SSF as forest cover fell below the 20% threshold of SSF in some data years. Unfortunately, while there are spatial layers representing corporate ownership of forests (Hewes, Butler, & Liknes, 2017), such data is not available for 2000, the year of our analyses. However, the relative effect of this shortcoming is expected to be minor because of the large spatial window used in this analysis and the fast growth rate (i.e., return to forest cover) of trees harvested under these systems in the US South.

Third, as mentioned in the results, the spatial location of SSF was robust when we changed the thresholds used to define forested lands (20%) and to distinguish wildlands from SSF (0.1 HU/km^2), but was quite sensitive to the upper threshold that distinguished SSF from (ex) urban lands. The housing threshold that we selected based on our expert panel was 10 HU/km^2, which is similar but distinctive to other studies (Supplemental material Table A1). For example, Radeloff et al. (2005) set the threshold between Wildland and Urban areas at 6.17 HU/km^2 and the Forests on the Edge study used 6.2/km^2 as the cut-off between rural and exurban (Stein et al., 2005), which corresponds to one house per 40 acres (Brown et al., 2010). While these studies sought a stable housing threshold that would reliably distinguish urban areas in the face of dynamic changes, we chose to include these populated forested regions that are increasingly in flux due to settlement and resource demands.

Fourth, of all the eight clusters identified by the exemplar method, the most puzzling was the Sparse Young cluster, which differed from other sparse clusters only by having a youthful population. A visual inspection of the locations of the Sparse Young clusters (Fig. 5) suggest the proportion of Native Americans might be a contributing factor related to this youthful character (e.g. the strong predominance in the Four Corners region of Arizona and New Mexico and the high frequency of Sparse Young in northern California, eastern Washington, western Montana, and central Minnesota: United States Census Bureau, 2010).

Fifth, although we identified some clear patterns in our two multivariate analyses that were organized along axes ranging from sparse to populated and from amenities to resource extraction, another primary finding of both multivariate analyses was the substantial overlap and variety of socio-economic factors within SSF. The fact that five axes were required to explain more than half of the variance is indicative of this high heterogeneity within SSF (Table A3). The same can be said for the spatial structure of this variation, which under an unconstrained analysis would have identified 1030 clusters. While there is a broad-scale geographic pattern that separates the southeastern US from the northern New England, the Great Lakes, and the Inter-mountain West, an equally striking pattern is the strong heterogeneity within a small geographic distance—a point we explore below. Further, many important socioeconomic variables such as poverty and age showed relatively weak patterns along either the principal components or the exemplar clusters.

4.2. Comparisons with previous work

In the introduction, we identified a common view of the importance of understanding SSF as intermediate land between wild and suburban areas with previous work on the WUI (Wildland Urban Interface) (Radeloff et al., 2010) and FOTE (Stein et al., 2005). However, unlike these studies, which conceptualized SSF as part of a gradient ranging from wild to suburban lands, we contend that SSF constitute a distinctive portion of the US. Our results showed a boundary between SSF and (ex)urban lands occurring at about 10 HU/km^2 (versus 6 HU/km^2 in FOTE and WUI) at which rapid development and population increase is converting SSF to suburban lands (Fig. 3), consistent with the FOTE/WUI view. However, our research also identified a much larger area of forested, sparsely populated lands ranging from 0.1 HU/km^2 to 10 km^2 that have remained in this category for the 20 years studied. Indeed, we showed that once the transition boundary is removed, core features like population and housing density are basically unchanged for 20 years. This suggests that SSF will continue to occupy almost 30% of all continental US lands and a majority (60%) of all forested lands, with (ex) urban and wildlands playing minor roles in future forested lands. Our results simultaneously confirm a focus on the rapidly changing boundary found in FOTE/WUI, and highlight the need for focus and study on those SSF that are stable in basic character and key demographic features.

4.3. SSF must be studied in more detail and at national scale

We argued in the introduction that many academic disciplines have failed to give due attention to SSF, either because of their preferences for agricultural lands (e.g., rural sociology) or for wildlands and urban lands (e.g, ecology). Our results identify clear reasons why these two disciplines might wish to give more attention to SSF.

Specifically, for ecologists we show that SSF represents more than 30% of the contiguous US and over 60% of the forested lands. As such SSF will be a critical resource for future conservation efforts of forest species, be they plants or animals (Colgan et al., 2014). Yet very few ecological studies are conducted in SSF (Martin et al., 2012). In comparison, wildlands represent less than 10% of all land in the US, but are studied much more frequently. Given that raw land area is a central factor in conservation (Rosenzweig, 1995), it is critical that SSF receive due attention (Colgan et al., 2014). The recent upswing of ecological studies in (sub)urban lands (Ahern, 2013) may be motivated by the view that this is the future of all lands. However, our results suggest that SSF will remain the most common category in future decades. It is also important to note that SSF contains lands with quite low housing densities (down to 0.1 HU/km^2). Although such sparse settlement can have some important impacts on wildlife due to localized industrial activity, roads (Ament, Clevenger, Yu, & Hardy, 2008), outdoor lighting (Longcore & Rich, 2004) and elevated noise levels (Barber et al., 2011), SSF have much more potential for conservation than more heavily settled lands.

Secondly, for rural sociologists, our results on the socioeconomic factors in SSF show a complex and varied socio-economic texture to SSF societal organization. Only 20% of the variance in our data is captured by the primary gradient from sparse to densely settled lands and the spatial structuring of the residual variation is extremely rich. Although we discovered some clear regional differences, the details of the fine-scale variation within regions are unexplored. Finally, we studied socio-economic patterns at a single point in time, so much work remains to be done on the dynamic nature of SSF communities. Further understanding of the variation between resource use and amenity economies and the spatial and economic constraints and temporal dynamics of transitioning between the two is of high practical importance (Morzillo et al., 2015). Our results highlight that SSF is a rich subject for Socio-Environmental Systems (SES) studies with considerable interplay between land uses and community structure.

We only analyzed the contiguous US, but SSF are a global phenomenon. Worldwide, an estimated 38.2 million people live in what can be considered forested biomes (Ellis & Ramankutty, 2008). While this represents a mere 0.6% of the population, afforestation and demand for amenity-rich land likely means that forest will continue to be inhabited, managed and impacted by people (Grau & Aide, 2008; Kauppi et al., 2006; Meyfroidt & Lambin, 2008). Forest area is decreasing on the whole (Lambin & Geist, 2008), but there are multiple examples of regionally-important increases in forest cover. Some estimates suggest that an area the size of France has returned to forest between 1995 and 2005 (FAO, 2006). In post-Soviet Russia alone more than 40 million ha of arable land was abandoned within 20 years (Prishchepov, Radeloff, Baumann, Kuemmerle, & Müller, 2012). Estimates for Latin America have placed afforestation-related abandonment at 36 million ha (Aide et al., 2013). These dynamics suggest that study of SSF is important globally.

4.4. Policy and management implications

The primary reason for the transition out of SSF is the expansion of urban areas in the eastern US (especially the southeast). Assuming urban centers will continue to grow in population, policies leading to denser rather than more sprawling housing patterns (e.g. growing up instead of growing out) seem important for both urban centers and to limit effects on SSF. Similarly, given that most territory lost from SSF existed in close spatial proximity to (ex)urban areas, it is easy to identify regions of SSF likely to convert to (ex)urban and these regions can, if they wish, adopt regional plans that aim to keep their housing density higher.

Secondly, specific areas might be given special attention due to their particular vulnerabilities and local conditions requiring policy suggestions that consider best possible transitions (Morzillo et al., 2015). Certainly, specific locations are better positioned to 'become' amenity landscapes, while others will continue to be resource extraction areas (e.g. mines, agriculture, timber), while still others will contend with urban pressures and be lost. Additionally, there are specific unique challenges related to declining population that clearly need appropriate attention and resources. However, geography alone (in the sense of distance from cities) is not destiny, and local communities may have choices of what type of economy and social fabric they wish to have (Morzillo et al., 2015). Our multi-scale findings of socioenvironmental differences may be an indication of heterogeneity in existing management and policy structures, which are likely to shape continued diversity in the design and efficacy of management strategies and policies.

5. Conclusions

We conclude by arguing that the rural communities found within SSF are an important part of American culture, an important part of the landscape quantitatively, and a non-trivial part of the population. As such, SSF are deserving of much more direct study, not simply in a relational sense defined where wildlands or (ex)urban regions end, but rather in their own right as a distinct landscape class. The socio-economic structure within SSF is simultaneously interesting, informative, and important but also complex. It is not clear why some regions of SSF are experiencing rapid change while others are more stable. To the extent policy makers care about managing this landscape and lifestyle, and we suggest that there are many reasons to do so, this paper gives some broad outlines of issues to consider. However, we also clearly recognize that this paper raises as many questions as it answers, and we hope that it inspires more work that sees SSF as a large and important part of the landscape not only in the United States, but also globally.

Acknowledgements

This work benefited from support from the National Socio-Environmental Synthesis Center (SESYNC) – NSF award DBI-1052875 and the NSF strategic program MAINE EPSCoR. We would especially like to thank Susan Stein, USDA National Agroforestry Center (NAC); Kenneth Young, Kennebec County Council of Governments, Maine; and Tom Spies, USDA Forest Service for contributing their insight to the definition of SSF. David Helmers generated the 10-km pixel grid and summarized census and land cover data. The exemplar cluster analysis was based on R code that was provided at an Exemplar Analysis workshop organized by Matthew Mitchell and Jeffrey Cardille. Thanks to Darla Munroe for introducing us to George and his valuable contribution. We also thank the two anonymous reviewers.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.landurbplan.2017.10.009.

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