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An exploratory spatial analysis of projected hotspots of population growth, natural land loss, and climate change in the conterminous United States

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ABSTRACT

Considering expected population growth and changes in landuse and climate, it is important to understand whether and where the relative change in one or more of these stressors will most likely impact natural and human systems. This study employed exploratory spatial data analysis of population growth, loss of natural land, and climate change data, all projected at county level for the conterminous United States as part of the USDA Forest Service's 2010 RPA Assessment. Location and geographical extent of projected significant "hotspots" of individual and multiple stressors were analyzed with respect to the location of at-risk natural ecosystems (protected lands, imperiled species) and the social and economic characteristics of human population within and outside the hotspots. While hotspots of projected climate change are broadly distributed across the Southwest, Northern Midwest, and Northeast, hotspots of projected natural land loss clustered in the Southeast and Pacific Northwest, and the primary area of overlap for multiple changes was the Southwest. Most counties in hotspots are currently home to higher numbers of at-risk or listed threatened and endangered (T&E) species than those outside. Also, up to three-quarters of the lands stringently managed to preserve their unique natural and scientific values are projected to be in hotspots of one or more stressors. Findings will be useful in identifying areas in which the greatest emerging land use management challenges will likely be concentrated due to change in one or more stressors. Findings will also inform land use planning decisions, and most importantly, provide information that will prioritize limited resources for mitigation, restoration, and management in areas of highest need. While our analysis shows notable differences in social and economic characteristics of counties projected to be in and outside hotspots, it also suggests the need for an in-depth study to compare sensitivity and adaptive capacity at community scale to compare the vulnerability of communities.

1. Introduction

Over the past few decades, various parts of the United States have experienced high population growth, changing migration patterns, and urbanization, which are often linked to land use and landscape change. Migration history in the United States reveals that population growth in the past was fueled primarily by economic opportunities (e.g., job, investment) in urban areas, which led to a remarkable trend of rural-to-urban migration (Carlino and Mills, 1987; Chen et al., 2014). More recently however, population growth in sub-urban and rural areas is starting to trend upwards with a surge in up-and-coming retirees and amenity migrants (Chi and Marcouiller, 2013; Poudyal et al., 2008). This new trend in amenity migration is often attributable to the opportunity to telecommute for work as well as a shift in public interest to live in rural communities that offer a variety of life amenities such as clean environment, less congestion and crime, and ample opportunities for outdoor recreation (Cordell et al., 2011; Chi and Marcouiller, 2013). These observations are echoed by a number of recent studies on land use change that attribute part of the gradual change

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in America's rural landscapes to population growth and amenity migration (Deller et al., 2001; Kim et al., 2005).

Continuous population growth and urban-rural migration is likely to expand the extent of the "human footprint" in natural lands. Footprint is a term often used, by both social scientists and ecologists alike, to describe the presence of as well as the collective stress of humans on the natural landscape (Cordell and Overdevest, 2001; Sanderson et al., 2002). In this paper, we describe population growth and natural land loss as two key "stressors" representing the human footprint, although our analysis further expands to a third stressor, climate change. A particular concern of footprint expansion in recent years has been the population growth near protected areas such as national parks, wilderness areas, national forests. For example, a historical analysis of development during 1940–2000 showed that 28 million new housing units were built within 50 km of protected areas, whereas the growth rate within 1 kilometer of protected areas outpaced the national average growth (Radeloff and Stewart, 2010). The same study also noted that among all kinds of protected areas examined, peripheral housing growth rate was highest (474%) in the case of wilderness areas, a class of protected area with highest priority for conservation. Similarly, many rural landscapes across the nation have experienced a gradual increase in wildland urban interface (WUI) areas, particularly in regions facing significant population growth and retiree in-migration (Hammer et al., 2009). The WUI areas are believed to be more vulnerable to wildfire, biodiversity impacts from invasive species, and human-wildlife conflict.

In addition to population growth and loss of natural land, climate change is increasingly considered an additional stressor of significant impact on natural and human systems (Gonzalez et al., 2010). Climate projection models have revealed a wide variation in climate change across the nation, which could mean that some communities may see relatively higher exposure to climate risks than others. In regions where the stress of climate change is expected to be concentrated, the effect of population growth and land use change could be further exacerbated by the direct and indirect effects of climate. Hence, long-term trend monitoring and growth pattern analysis can be useful in recognizing the vulnerable and critical areas across landscape (Martinez-Fernandez et al., 2015).

Earlier, Cordell and Overdevest (2001) conducted a broad-scale nationwide assessment of trends and pattern in population growth and land development in the US. Their work primarily involved an examination of demographic, urban, rural, economic, leisure and recreation, and population trends of the United States, focusing on changes in these trends over time and space. A related study by Hammer et al. (2004) characterized the spatial and temporal pattern of housing development utilizing data from the second half of the previous century in the North Central United States. However, a more comprehensive regional analysis of multiple stressors is required to understand the regional variation in growth and change pattern. For example, the land use change rate nationwide could be stable, but there may be a group of contiguous countries exhibiting a high growth "cluster." As long as such clusters appear not just by random chance but because of some spatial phenomenon on the ground, it may warrant a regional effort to address growth management and land use planning. Similarly, if there is a cluster of counties that are projected to experience higher than average increase in temperature, vulnerable biological species in those areas could be closely monitored for early warnings of climate stress on natural community (Midgley et al., 2002). Over time, it is reasonable to expect some level of change in each type of stressor (i.e., population growth, landuse change, climate change) almost everywhere. However, understanding whether and where change in one or more of these stressors will concentrate, as well as how the areas of such concentration relate to natural and human communities of interest would be important in conservation planning and prioritization of efforts for mitigation and adaptation at various geographical scales. Identifying clusters of priority needs is important because a mismatch between planning or management efforts and the vulnerability pattern of natural and human community could seriously jeopardize the effectiveness of programs designed to address problems.

Despite substantial literature on the historical analysis of population demography and land use modeling, little research has been done to analyze the projected trends and patterns for the future. Some studies have been done to visualize the historical trends and future patterns of a single stressor (e.g., climate change) at a global scale (see Gonzalez et al., 2010). A more recent study conducted at the global level by Eigenbrod et al. (2015) has assessed vulnerability to climate change at different spatial scales and identified the areas of priority for conservation at continental and regional level. Their result suggested that conservation priority should be given to large-scale refugia in areas of nature-dominated landscapes in Africa, Australia, and South America, whereas fine-scale refugia should be priority for conservation in human-dominated landscapes in Europe, North America, and Southeast Asia. While these studies conducted at the global level offer valuable insights in identifying the regions of global conservation priority, a national level analysis will be required to locate landscapes needing priority for national and regional efforts. Exploratory studies identifying local clusters of change in population growth and land use have provided valuable input in evaluating land use policies (Kroll and Haase, 2010).

The overarching goal of this study was to identify and visualize the "hotspots"[1] of the three key stressors (i.e., population growth, loss of natural land,[2] and climate change) during the period of 2010–2060, and then examine their regional pattern in relation to critical biodiversity habitat, at-risk species, and human communities. As discussed in the introduction, population growth and loss of natural land were noted as two key measures of human footprint, and climate change was also included in the analysis to explore the potential vulnerabilities of landscapes and communities to a more recently identified threat. Spatially explicit systematic analyses were implemented to focus on where natural lands are likely to be affected by human pressures and global climate change. Spatial statistics tools that are based on spatial autocorrelation and spatial interactions among counties were used to identify hotspots of change. While this approach does not explain the cause and effect, it helps in systematically mapping the geographical concentration of local and ambient change in one or more phenomena as well as the local level association among various indicators of human footprint and other stressors. To achieve this goal, the analysis first examined the areas where hotspots of one or more stresses coincide, then compared the characteristics of biodiversity, habitat, at-risk species population, and location inside and outside the hotspots of various types.

2. Methodology

2.1. Exploratory spatial data analysis

Hotspots of individual stressors were located with a series of exploratory spatial data analysis (ESDA), a spatial econometric tool widely applied in regional analysis (Anselin, 1995). ESDA involves calculating local indicator of spatial association (LISA) Statistic at

[1] A hotspot is a group of adjacent areal units that observe higher than average rate of change in a given phenomenon (e.g., population).

[2] Natural land, for the purpose of this study, are areas that are neither developed nor cultivated; and therefore included forestland and rangelands.