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ORIGINAL RESEARCH

Managing the Forest Landscape: Exploring the Quantitative Interplay Between Forestland Patches, Areas and Landowner Numbers in Counties from Alabama, USA

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Abstract
Forestlands provide timber resources and valuable ecosystem services. To better manage forest landscape and develop policies, it is important to quantify the relationships between the number of forestland patches, patch areas, and landowner numbers. By using integrated analysis of information about the forestlands in 17 counties in Alabama, USA, similar scaling relationships are determined in the forestland patch quantity, areas, and owner numbers across various patch-size classes. Forestlands on individual properties of up to 50 acres cover about 59% of patch number and 21% of total area, encompassing 77% of landowner numbers. In Alabama, few private landowners have more than 500 acres of forestland. Similar relationships between different sizes of forestlands and the accumulated percentages of patch quantity, areas, and landowner numbers exist. These distribution relationships can be described by quadratic and power functions. A significant correlation exists between forestland prices and the exponents of these scaling relationships in forest patch numbers, total areas, and landowner numbers across counties. These results provide a new understanding of the distribution of forestland in Alabama. The implication is that an economic approach (e.g., adjusting forestland prices or taxes) may help to better manage the remaining forest landscape and develop conservation policy in this region that could be used to reduce forest fragmentation.

Keywords Forest landscape · Fragmentation · Land price · Scaling relationship · Socioeconomic factors

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Introduction

Forestlands bring not only direct income to landowners through timber sales, but also provide many intangible ecosystem services to society—such as absorbing atmospheric CO_2 for carbon sequestration, providing habitat for wildlife, providing recreational opportunities, regulating local climate, and protecting water and air quality (Millennium Ecosystem Assessment 2005; Chen 2016). Change of forest landscape structure (e.g., land patches and their areas) or number of landowners may affect the sustainability of ecosystem services because of non-linear responses from both natural and socioeconomic interactions, such as the forest fire regime and risk through changing tree species or management practices (Chen 2007; Sutherland et al. 2016; Butsic et al. 2017). Forestland parcelization and fragmentation can lead to the loss of wildlife habitat and timber, decreased water quality, and loss of recreational access (LaPierre and Germain 2005). Some of these ecological values are not necessarily reflected in the market, but awareness of their socioeconomic and political relevance is growing. Thus it is necessary to manage forest landscape across a large scale, especially for the emergent patterns and ecological regime shifts.

Because private forestland covers about 430 million acres in the USA (Best 2002), forestland management or ownership change has the potential to change forest landscape structure and coverage pattern, which may lead to altered ecological functions (Wear et al. 1996; Chen and Fraser 2009). For example, a large tract of forest land can support more wildlife species than several small and isolated pieces. From an economic perspective, all forest landowners in the USA are subject to local, or state, or federal taxes. When property taxes increase, such as at the urban and rural interface, the benefits of growing forests and trees are less than the expense of holding a piece of land and paying annual taxes, and the forest landowners are likely to sell part or all their properties or change land use despite personal objectives ranging from timber production to preservation of a family legacy (Butler et al. 2012). In turn, this could lead to increased forest fragmentation and decreased area of forest lands, which can affect local or regional ecological processes.

After studying the land ownership and forest coverage across 66 watersheds in the state of Oregon, Stanfield et al. (2002) concluded that patterns of land ownership and forest coverage were related in significant ways. Spatial patterns in many landowners' motivations and behaviors (e.g., harvesting forest or forest land sale) could be related to underlying similarities and differences in biophysical, social, and economic factors in the southern forests of the USA (Poudyal et al. 2019). Traditionally, only the total (or average) area of a forest landowner was considered, but its spatial condition was neglected, such as whether the land was separated into several disconnected patches. When the landscape becomes fragmented, more small patches appear. Therefore, it is important to monitor and study the patterns of forestland patches, their areas, and landowner number in a region to analyze their relationships with socioeconomic factors.

Alabama has the third largest commercial forest industry in the USA because of its diverse and abundant forest resources (Phillips 2006). Tree species richness in Alabama have been documented to vary from 145 to 193 species. In Alabama, the total forest area is approximately 9.3 million ha, covering roughly two-thirds of the State (www.forestry.alabama.gov). Timber production, including the production of sawn timber, pulpwood, and fuelwood, and non-timber production, such as for hunting game, are typical objectives for private forest landowners in Alabama (Gan et al. 2003; Fraser et al. 2005; Pan et al. 2007). In this area, poor landowners may be more likely to harvest timber or sell their forestlands because this can bring income (Alig et al. 1990). Previous studies reported that 5% of private landowners in Alabama own less than 8 acres on average (McNabb and Bliss 1994), while 32% hold less than 51 acres (Zhang et al. 1998; Pan et al. 2007). Satellite images indicated a higher rate of deforestation and pattern change in private forests in Alabama (Li et al. 2009). It is believed that multiple factors, including human population density, age structure, urban–rural population structure, income sources, and land tenure type, are associated with forestland size distribution at the county level (Pan et al. 2009). The complicated interactions, such as different forest harvest and burning regimes, may alter ecological processes. Typically, commercial forest coverage, such as that of pine plantations, increases in counties with a relatively weak economy (Chen 2010, 2019).

Further research on the general and quantitative patterns of forestland patches, areas, and owner numbers across counties in Alabama is needed. The hypothesis is that a general scaling relationship may exist and can quantitatively describe the complicated forestland and owners across counties. This type of synthetic analysis would help to uncover the primary social and economic relationships driving forestland distribution in the State of Alabama. Thus, the specific objectives of this study were to find (1) whether there are general and quantitative patterns in forestland patches, areas, and landowner numbers in Alabama counties; and (2) whether there are some main social and economic factors related to the general patterns of forest land. Understanding the general patterns and possible mechanisms may provide better information for managing forest landscape and developing new policies in Alabama or all of the southern region of the USA.

Research Method

Forestland information, including sites, areas, and landowners (e.g., name and address), was obtained from Alabama GIS (www.alabamagis.com), that was based on Plat maps showing the divisions of a piece of land and of the landowners. The Plat maps were developed by the United States General Land Office (www.en.wikipedia.org/wiki/Plat). Due to limited forest information from the other fifty counties, 17 counties were included in this study (Table 1). The forestlands were all privately owned and the ownership included individuals and companies. The details from the GIS of each county include patch numbers of forest land (or called as patch quantity), location, the area of each forestland patch, owner information, land value, and price. Land patch number, area, and landowner number represent three different characteristics of the forest landscape. Social and economic data, such as population and income, were obtained from census data.

Table 1 Background forestland information for 17 counties included in this study

County	Patch quantity	Total area (acres)	Forest landowner number (individuals)
Autauga	5414	337,204	2043
Bibb	4673	382,476	2143
Chambers	4887	394,344	2109
Cleburne	6483	480,719	1907
Coosa	1128	58,840	612
Covington	4476	262,372	2741
Crenshaw	6690	405,388	2573
Fayette	9920	404,709	3858
Geneva	6170	466,559	2209
Lamar	9246	516,180	3092
Lowndes	2974	326,284	1215
Marengo	6884	623,020	2515
Perry	35	1800	25
Pike	44	1836	30
Russell	2765	317,315	1198
Sumter	8222	906,993	2161
Wilcox	11,192	1,195,873	1974

The frequency distribution of patches was used to characterize the number of specific groups and general distribution trend of land patches along with varied patch sizes in each county. Numbers of forestland patches in 50-acre size classes, including up to 50 acres, over 50–100 acres, and so on up to over 650 acres, and the total areas of forestland in these categories of patch size, as well as the number of landowners, were counted using GIS of forest coverage in each county. Repeated owners were only counted once in the numbers of landowners in each category. Accumulated percentages of various patch number (pieces), area (acres), and landowner number (individuals) were calculated based on the rates in the various classes. This accumulated percentage shows the general distribution of varying land patches, areas, and owner number in the overall patterns. The critical land scale (in acres) is defined as the spatial scale, which can reach 90% in the accumulated percentages in patch quantity, total area, or landowner numbers. This concept can be used to describe whether the forestland in a county is close to a critical condition. A low value in critical scale means a low threshold to reach 90% of patch numbers, total areas and owner numbers.

The ecological scaling relationship, which means the relationship that can be extrapolated to other scales (e.g., spatial), is often described by power functions. A power function in statistics is a functional relationship between two variables ($y = ax^b$, where x is an independent and y a dependent variable), for which a relative change in variable x results in a proportional change in variable y, independent of the initial size of those variables (Bar-Yam 2011). One attribute of this scaling relationship is the scale invariance, which means the results from a small scale can be extrapolated to a larger extent. Thus, they are also called power laws. Comparing the scaling relationships (exponents) in forestland across spatial scales among different counties could indicate new information, such as the regime of integrated interactions in an area. This concept has been widely used in forest ecology (e.g., by Chen et al. 2017; Chen 2018). A power function can be changed into a linear relationship if the two variables on logarithmic axes are presented in a plot, such as $\log(y) = b*\log(x) + \log(a)$. Plotting two variables against each other in this way is how generally to determine if there is a power scaling relationship. Correlation analysis for power exponents in patch number, area, and owner number and their relationships between each other and the socioeconomic conditions across counties was conducted by using the least-squares regression from SAS software. The statistical test was found significant at $p < 0.05$.

Results

Power scaling relationships exist in the forestland patch quantity, areas, and also landowner numbers across different patch size classes with similar exponents (Table 2), with Autauga County serving as a typical example (Fig. 1). Most of the exponents concentrate around −1.6 to −3.2, −0.8 to −1.9, and −2.0 to −3.2 for patch numbers, total area, and owner numbers, respectively. The similar values may indicate similar regime for the forestland distribution in these counties, while the negative values mean smaller numbers in patches, patch areas, and landowners with the increase of patch size. However, the relationships regarding the total areas at Bibb, Perry, Pike, Russell, and Sumter counties are not statistically significant. Generally, as the patch size of forestland increases for a county, there are fewer patches, lower total areas, and fewer landowners. Overall, forestlands no larger than 50 acres cover about 59% of patch quantity, 21% of the total area, and 77% of landowner numbers (Fig. 2). Forestlands larger than 500 acres have low levels for patch quantity, total area, and landowner numbers across counties (Fig. 3). These large forestlands (larger than 500 acres) cover about 25% of the total forestland in Bibb County and 20% in Russell County, but no forestlands larger than 500 acres are found in Perry and Pike counties.

By using accumulated percentage, the relationships between different scales of forestland and the proportion of forestland patch quantity, areas, and owner numbers are found to follow an “S” shape, such as those for Autauga County (Fig. 4). Both power and quadratic functions are observed in each county (Table 3). The power exponents are concentrated around 0.1–0.28 for the percentages of patches, 0.3–0.8 for the percentages of total areas, and 0.02–0.08 for the percentages of landowner numbers. The critical scale to cover 90% of forest patch quantity, total areas, or landowner numbers varies with the study items and counties (Fig. 5). The critical scale for the percentage of total area, patch numbers, and owner numbers is about 500 acres, 200 acres, and 100 acres, respectively.

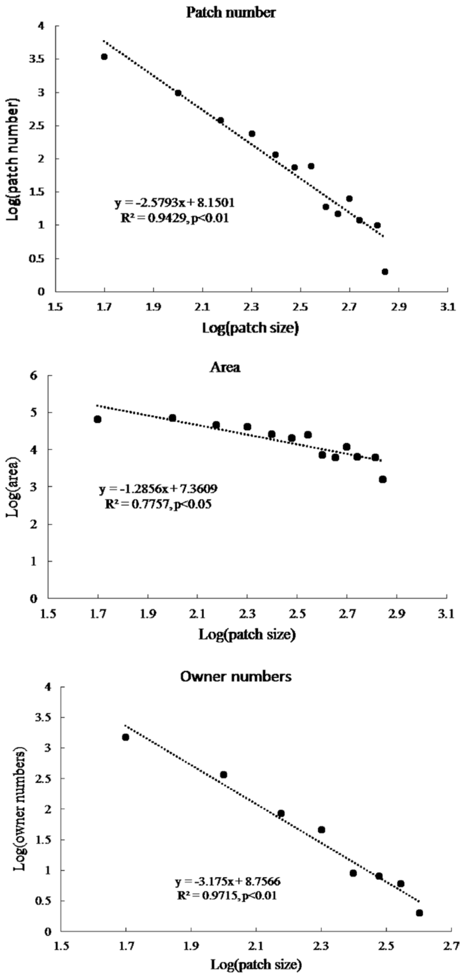
There are significant correlations among the power exponents in forest patches, areas, and owner numbers (Fig. 6). The changes in forest patches, areas, and owner numbers have different regimes (different power exponents) in different counties.

Table 2 Power exponents in forestland patch quantity (pieces), total area (acres) and forest landowner number (individuals) in selected Alabama counties

County	Patch quantity	Total area	Forest landowner number
Autauga	−2.5793 $R^2=0.9429$, $p<0.01$	−1.2856 $R^2=0.7757$, $p<0.05$	−3.175 $R^2=0.9715$, $p<0.01$
Bibb	−1.8876 $R^2=0.8706$, $p<0.01$	−0.6533 $R^2=0.4505$, $p>0.05$	−2.9547 $R^2=0.8935$, $p<0.01$
Chambers	−2.2955 $R^2=0.9383$, $p<0.01$	−1.0692 $R^2=0.7278$, $p<0.05$	−3.1818 $R^2=0.9561$, $p<0.01$
Cleburne	−2.4066 $R^2=0.9679$, $p<0.01$	−1.189 $R^2=0.8366$, $p<0.05$	−3.5212 $R^2=0.98$, $p<0.01$
Coosa	−2.4709 $R^2=0.9582$, $p<0.01$	−1.1779 $R^2=0.8173$, $p<0.05$	−2.6021 $R^2=0.9609$, $p<0.01$
Covington	−2.5332 $R^2=0.9099$, $p<0.01$	−1.3666 $R^2=0.7636$, $p<0.05$	−3.242 $R^2=0.9414$, $p<0.01$
Crenshaw	−3.1288 $R^2=0.9277$, $p<0.01$	−1.9329 $R^2=0.8074$, $p<0.05$	−3.7966 $R^2=0.9718$, $p<0.01$
Fayette	−3.1596 $R^2=0.9632$, $p<0.01$	−1.8716 $R^2=0.8754$, $p<0.05$	−4.1204 $R^2=0.9931$, $p<0.01$
Geneva	−2.5199 $R^2=0.9033$, $p<0.01$	−1.3373 $R^2=0.7127$, $p<0.05$	−3.6563 $R^2=0.9552$, $p<0.01$
Lamar	−2.979 $R^2=0.9678$, $p<0.01$	−1.7503 $R^2=0.8825$, $p<0.01$	−3.8866 $R^2=0.9863$, $p<0.01$
Lowndes	−1.7838 $R^2=0.9571$, $p<0.01$	−0.5667 $R^2=0.6117$, $p<0.05$	−2.7797 $R^2=0.9329$, $p<0.01$
Marengo	−2.0452 $R^2=0.9586$, $p<0.01$	−0.8487 $R^2=0.7594$, $p<0.05$	−3.2107 $R^2=0.9829$, $p<0.01$
Perry	−3.44 $R^2=0.7689$, $p<0.05$	−0.4141 $R^2=0.0563$, $p>0.05$	−1.3114 $R^2=0.4801$, $p>0.05$
Pike	−1.6439 $R^2=0.7667$, $p<0.05$	−0.3524 $R^2=0.1878$, $p>0.05$	−1.9803 $R^2=0.8464$, $p<0.05$
Russell	−1.6996 $R^2=0.8589$, $p<0.05$	−0.4199 $R^2=0.2414$, $p>0.05$	−2.3049 $R^2=0.9499$, $p<0.01$
Sumter	−1.6661 $R^2=0.943$, $p<0.01$	−0.437 $R^2=0.4858$, $p>0.05$	−3.0293 $R^2=0.9792$, $p<0.01$
Wilcox	−1.8441 $R^2=0.9677$, $p<0.01$	−0.6631 $R^2=0.7461$, $p<0.05$	−3.2745 $R^2=0.9675$, $p<0.01$

However, these regimes are also correlated with each other. This result may indicate the intrinsic quantitative relationships between forestland patches, areas, and owners across different counties. It is possible to use one variable to estimate the other two based on the scaling relationships. A significant correlation also exists between forestland prices and the power exponents in forest patch numbers, total areas, and numbers of landowners across these counties if Perry County is excluded (Fig. 7). This result means the land price is significantly related to the forest landscape (patches and areas) and number of landowners. The higher the land price, the lower the power exponents for patch quantity, areas, and landowner numbers.

Fig. 1 The relationships between different patch sizes and forest land patch quantity, areas, and landowner numbers in Autauga County



Discussion

Forest landscape management emphasizes the integrity of ecological processes between forest patches and landowners (Chen and Fraser 2009; Chen 2017). Despite different forest landscape patterns, there is a general tradeoff among forest landscape, landowners, and socioeconomics in Alabama counties. This emergent trend is shown by the similar power exponents in forest patch numbers, areas, and owner numbers across different counties. If the information of historical forestlands is available, the time of change could be detected (Chen et al. 2010). This result is consistent with Pan et al. (2009). The deviations in exponents may indicate different regimes. In these Alabama counties, there are many small forestland patches and many landowners, such that forest areas of up to 50 acres account for approximately 59% of forest land patches and include 77% of landowners. Forestlands no less than

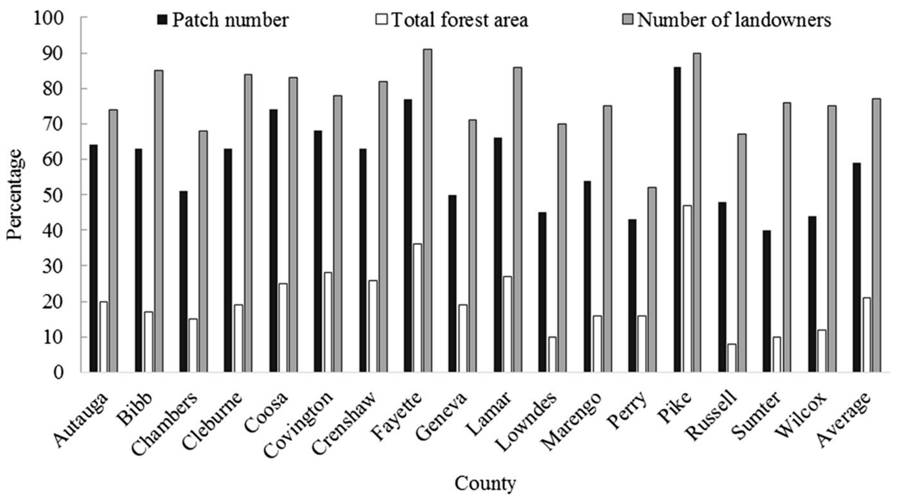


Fig. 2 Percentages of the forestland no more than 50 acres in forestland patch quantity (pieces), total forestland area (acres) and forest landowner number (individuals) in each county

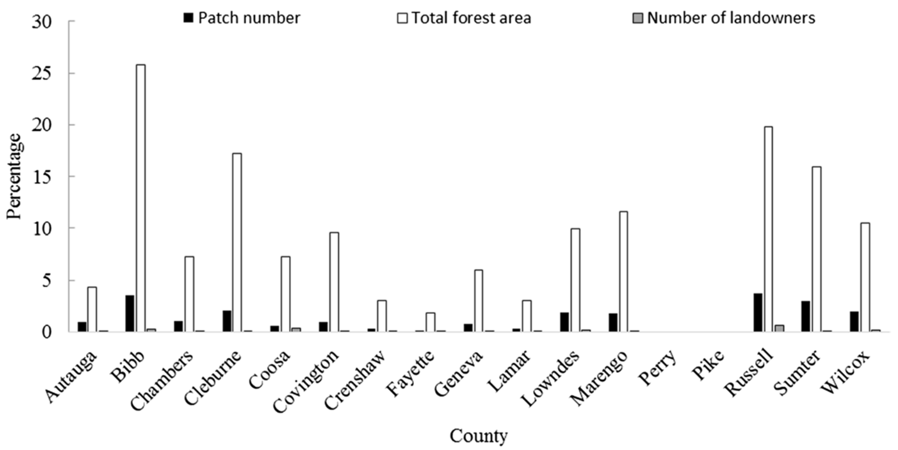


Fig. 3 Percentages of the forestland no less than 500 acres in forestland patch quantity (pieces), total forestland area (acres) and forest landowner number (individuals) in each county

500 acres are scarce in the counties of Alabama. The quantitative approach applied in this study is based on this complex condition.

Various factors are responsible for the fragmented patterns in forestland in this region. Economic factors (e.g., income and tax) are considered important (Butler et al. 2012). As all forestlands are taxable, when property taxes increase, if the cost of holding a large piece of land (e.g., annual taxes) becomes more than the benefits from the forest, then landowners may likely sell part or the entirety of their forestland (Pan et al. 2009). Landowners have to be sufficiently wealthy to purchase or

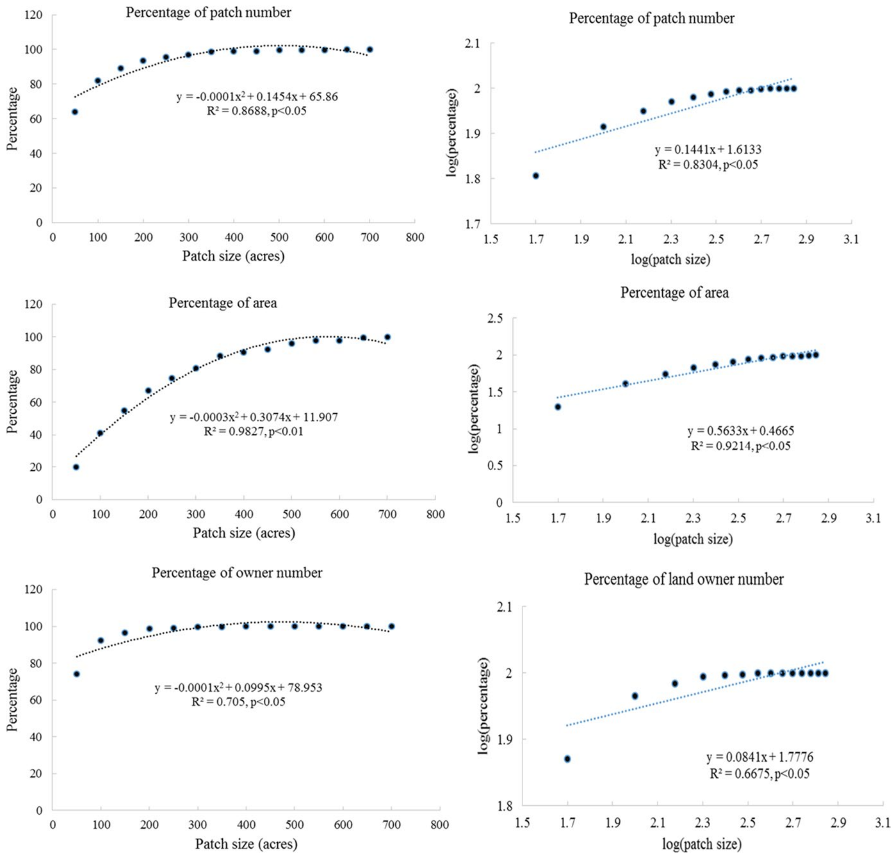


Fig. 4 Quadratic relationships and power functions between different patch sizes and the accumulated percentage in forestland patch quantity, areas, and landowner numbers in Autauga County

maintain a large piece of forest land. However, the wealth distribution among people usually follows a power function (Levy and Solomon 1997), which show that a small number of people own most of the wealth while most people are poor. This fact may be the cause for various scaling relationships in forestland patch numbers, areas, and landowner numbers. It is self-organization in the socioeconomic system (e.g., county). Global forests also follow power scaling in patch quantity, such as the most pieces of land in small sizes and only a small number with large pieces and the mean power exponent is 1.967 (Saravia et al. 2018), which is quite different from that observed in Alabama counties.

Historical factors also play a role in the forestlands in Alabama. Because of poor financial performance for the forest products industry, companies selling traditional vertically integrated forest products (e.g., a supply chain) had to sell over 18.3 million acres of forestlands in the early 2000s. This strategic change and timberland transactions also affected the forestland distribution in the southern region (Clutter et al. 2005). In addition, population growth, an increase in number of older people

Table 3 Parameters of quadratic relationships and power exponents between different forestland sizes (acres) and the accumulated percentage of patch quantity (pieces), total area (acres) and forest landowner number (individuals) in Alabama counties (all $p < 0.05$)

County	Percentage of patch quantity		Percentage of the total area		Percentage of forest landowner number	
	Quadratic	Power	Quadratic	Power	Quadratic	Power
Autauga	− 0.0001, 0.1454 $R^2=0.8688$	0.1441 $R^2=0.8304$	− 0.0003, 0.3074 $R^2=0.9827$	0.5633 $R^2=0.9214$	− 0.0001, 0.0995 $R^2=0.7050$	0.0841 $R^2=0.6775$
Bibb	− 0.0001, 0.127 $R^2=0.8708$	0.1499 $R^2=0.8853$	− 5E−05, 0.1501 $R^2=0.9625$	0.6037 $R^2=0.9759$	− 6E−05, 0.0568 $R^2=0.6748$	0.0468 $R^2=0.6650$
Chambers	− 0.0002, 0.2202 $R^2=0.8795$	0.2256 $R^2=0.8199$	− 0.0003, 0.3461 $R^2=0.978$	0.6647 $R^2=0.9065$	− 0.0002, 0.1456 $R^2=0.7785$	0.1207 $R^2=0.7208$
Cleburne	− 0.0001, 0.135 $R^2=0.8699$	0.147 $R^2=0.8613$	− 0.0001, 0.2112 $R^2=0.9718$	0.5728 $R^2=0.9665$	− 6E−05, 0.059 $R^2=0.6737$	0.0469 $R^2=0.6472$
Coosa	− 0.0001, 0.1047 $R^2=0.888$	0.101 $R^2=0.8669$	− 0.0002, 0.2714 $R^2=0.9867$	0.5037 $R^2=0.9561$	− 7E−05, 0.0702 $R^2=0.8047$	0.0594 $R^2=0.7743$
Covington	− 0.0001, 0.1226 $R^2=0.7854$	0.1182 $R^2=0.7661$	− 0.0002, 0.2272 $R^2=0.9305$	0.4194 $R^2=0.9065$	− 9E−05, 0.0862 $R^2=0.7127$	0.0723 $R^2=0.6824$
Crenshaw	− 0.0001, 0.1344 $R^2=0.7784$	0.135 $R^2=0.7373$	− 0.0002, 0.2737 $R^2=0.9373$	0.4327 $R^2=0.8545$	− 0.0002, 0.1416 $R^2=0.8268$	0.0528 $R^2=0.6245$
Fayette	− 0.0001, 0.0986 $R^2=0.7979$	0.081 $R^2=0.7654$	− 0.0003, 0.2723 $R^2=0.9438$	0.3537 $R^2=0.8883$	− 0.0002, 0.1047 $R^2=0.871$	0.0279 $R^2=0.6333$
Geneva	− 0.0002, 0.2189 $R^2=0.8173$	0.2149 $R^2=0.7517$	− 0.0003, 0.3264 $R^2=0.9405$	0.5508 $R^2=0.8561$	− 0.0005, 0.2657 $R^2=0.8531$	0.0973 $R^2=0.6395$
Lamar	− 0.0001, 0.1366 $R^2=0.8026$	0.1269 $R^2=0.7583$	− 0.0003, 0.2936 $R^2=0.943$	0.4358 $R^2=0.8664$	− 0.0002, 0.1268 $R^2=0.8349$	0.0402 $R^2=0.6203$
Lowndes	− 0.0002, 0.2367 $R^2=0.9598$	0.2901 $R^2=0.9237$	− 0.0002, 0.3 $R^2=0.9982$	0.8718 $R^2=0.9711$	− 0.0002, 0.176 $R^2=0.8803$	0.1188 $R^2=0.7852$
Marengo	− 0.0002, 0.1797 $R^2=0.9127$	0.2068 $R^2=0.8824$	− 0.0002, 0.264 $R^2=0.9924$	0.671 $R^2=0.966$	− 0.0001, 0.1061 $R^2=0.7409$	0.0807 $R^2=0.6854$
Perry	− 0.0019, 0.8547 $R^2=0.9799$	0.5581 $R^2=0.947$	− 0.0013, 0.8327 $R^2=0.9689$	1.2078 $R^2=0.9681$	− 0.0019, 0.8309 $R^2=0.9664$	0.4413 $R^2=0.9187$
Pike	− 0.0001, 0.0898 $R^2=0.9413$	0.0667 $R^2=0.9559$	− 3E−05, 0.1397 $R^2=0.9058$	0.319 $R^2=0.9327$	− 0.0001, 0.0738 $R^2=0.8698$	0.0481 $R^2=0.8736$
Russell	− 0.0002, 0.1864 $R^2=0.9572$	0.2571 $R^2=0.9463$	− 0.0001, 0.2177 $R^2=0.9949$	0.9423 $R^2=0.9833$	− 0.0001, 0.1365 $R^2=0.8863$	0.1359 $R^2=0.8565$

Table 3 (continued)

County	Percentage of patch quantity		Percentage of the total area		Percentage of forest land-owner number	
	Quadratic	Power	Quadratic	Power	Quadratic	Power
Sumter	−0.0002, 0.2064 $R^2=0.9343$	0.2787 $R^2=0.9124$	−0.0002, 0.2559 $R^2=0.993$ $R^2=0.9708$	0.8521 0.8521	−0.0001, 0.1056 $R^2=0.7913$	0.086 $R^2=0.7505$
Wilcox	−0.0002, 0.2428 $R^2=0.9318$	0.2886 $R^2=0.8843$	−0.0002, 0.3008 $R^2=0.995$	0.7894 $R^2=0.9577$	−0.0001, 0.1116 $R^2=0.7763$	0.0898 $R^2=0.7308$

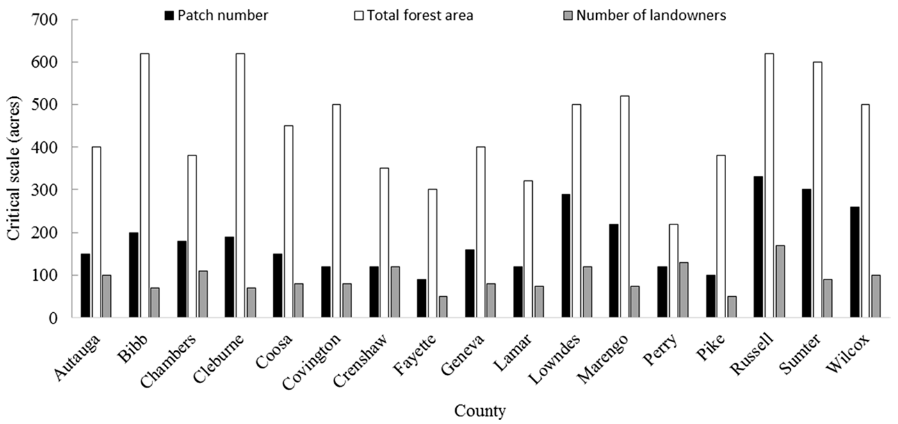


Fig. 5 Critical scale (acres) to include 90% of the forestland patch quantity (pieces), total areas (acres), and landowner number (individuals) in Alabama counties

who moved from northern States to warmer rural regions in Alabama and purchased higher numbers of small households, makes a contribution to this pattern. This is called parcelization, which happens when a large forest tract held in single ownership is divided into smaller parcels with many owners (Alig 1986; Pan et al. 2009). Older people may also make the legacy effect, which means they split up their lands between children (Butler et al. 2012). A high percentage of small parcel lands can easily cause forest fragmentation owing to land-use change. Li et al. (2009) confirmed the high vegetation changes in private lands through satellite images.

A critical concept in this study is the forestland patch, which characterizes the spatial condition of forestlands (i.e., disconnection or fragmentation). Smaller patches of isolated forestland have been considered to be one of the greatest threats to biodiversity conservation (Rosenberg and Raphael 1986). A study by Wintle et al. (2019) indicates that these small and isolated patches are extraordinarily important for biodiversity conservation. In order to decrease parcelization and fragmentation in forestland, larger and intact forestlands should be conserved with their surrounding areas. Fragmented forestlands need to be functionally restored through cooperative

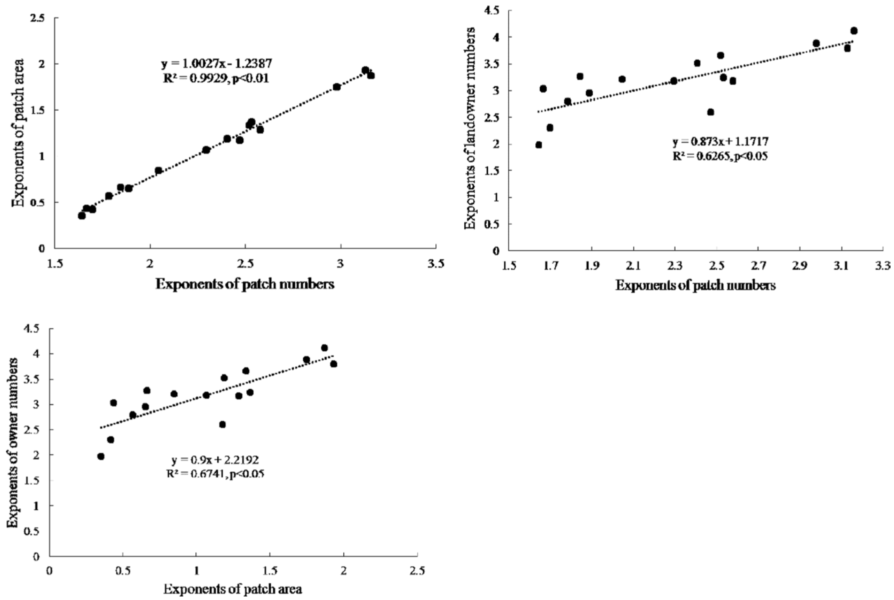


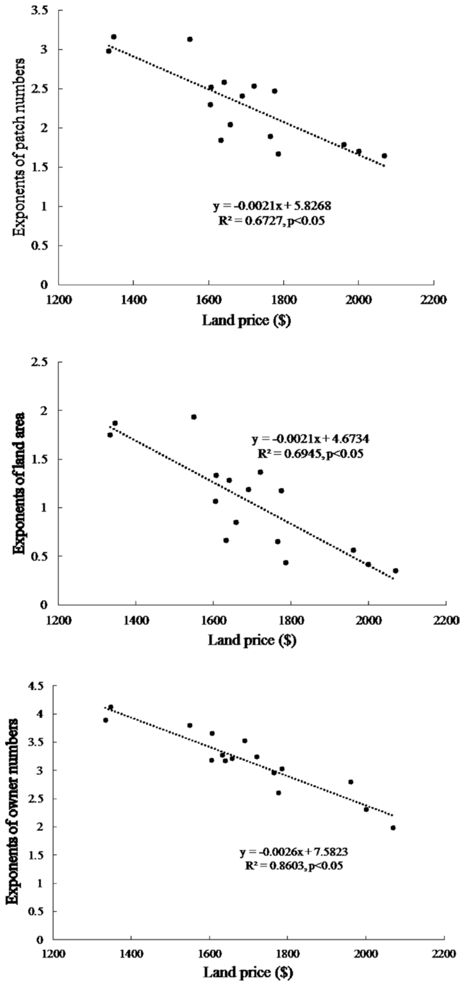
Fig. 6 Correlations among the power exponents in forest patches, areas, and landowner numbers in Alabama counties

stewardship mechanisms at a landscape level (Best 2002). Some landscape metrics, such as mean patch size, may provide an indicator of parcelization and fragmentation at local scales (Kilgore et al. 2013). The method used in this study (e.g., scaling relationship) may help to statistically monitor the parcelization and fragmentation for a large area (e.g., a county).

Using the accumulated percentage can find the relationships between scales of forestland patch quantity, areas, and owner number. All these relationships follow a similar trend of "S" shape, in which the accumulated percentage is saturated at a specific scale. Here, the spatial scale, which can include 90% in land patch quantity, areas, or landowner numbers, is used as a critical scale. These critical scales may be helpful for native forest landscape management and conservation in the counties of Alabama. Generally, both quadratic and power functions can also fit all these relationships across the counties. However, a quadratic relationship needs two parameters, while a power scaling only needs one. These similar quadratic relationships may also show a similar regime in the processes of forestland distribution and conversion in Alabama counties. Power exponents can easily indicate the regime, which may be linked to the socioeconomic mechanisms. Poudyal et al. (2014) suggested that landowners' decisions to convert forests to other land-covers are influenced mainly by sociodemographic factors (e.g., enrolling in cost assistance programs), ownership motivation, and expected financial returns from forestry and alternative land use.

Power exponents usually show the system underlying self-organizing processes (Marquet et al. 2005; Chen et al. 2017). There are significant correlations among

Fig. 7 Correlation between the forestland prices and the power exponents in forest patch numbers, areas and landowner numbers in 17 Alabama counties except for Perry County



the power exponents in forest patch numbers, total areas, and owner numbers. These exponents may reflect similar or correlated regimes in forest land distribution across these Alabama counties. Still, they are quite different from that of the global forests (Saravia et al. 2018), which may be due to the different spatial scales and local socioeconomic settings. In this study, these power exponents are not significantly correlated with population, per capita income, mean household income, or household numbers across the counties. However, unit land price shows a significant correlation with these power exponents. This relationship means the unit land price is correlated with the distribution of forest patch numbers, total areas, and landowner numbers. The mechanism may be understood as follows: when forest land prices are low, more people can purchase land in various pieces. Conversely, when forestland price is high, only a few people or companies can buy small numbers of large tracts. This result is consistent with the explanation from economic factors (Butler et al. 2012).

Variations in rural land value in Alabama are related to location (near cities of more than 25,000 population), distance to a public transportation facility, land physical properties (soil type, topographic feature, and water availability), and tract size (Spurlock and Adrian 1978). Urbanization and land development can increase the local land price and thus affect local forestland distribution and biodiversity conservation (Hansen et al. 2005; Mondal et al. 2013). Income inequality, land, and wealth are considered to promote agricultural expansion or deforestation in Latin America (Ceddia 2019). Although other factors (mortality rates, population density, income, and urbanization) may also contribute to forestland change (Pan et al. 2009; Zhang et al. 2009), maintaining suitable or similar forestland prices through policy intervention may be necessary for keeping forestland presence at the county level.

Conclusions and Policy Implications

Forest lands in Alabama are a complex mosaic with a high number of small land patches and landowners. This pattern is an obstacle to broad-scale landscape planning that some landowners may not change land use in order to achieve regional ecological services (e.g., carbon storage, wildlife habitat, and high water quality) and environmental conservation. Developing a complete understanding of the complicated relationships between forest land area, patch quantity, and landowner numbers will be invaluable for making decisions about forest land use and policy for the future. The existing power scaling relationships in the forestland patch quantity, areas, and landowner numbers in some counties of Alabama could be linked to similar social and economic institutions at the local level. The correlation between forestland prices and the power exponents of forest patch numbers, total areas, and landowner numbers might provide new ideas for changing forestland distribution and implementing environmental conservation via economic approaches, such as enhancing the role of forestland prices or taxes on forestry development including forest ecological values. This research may provide a case study for exploring empirical relationships between forest landscape patterns and combined socioeconomic forces. These results illustrate the importance of understanding the integrated effects of socioeconomic forces manifested in the landscape patterns. The limitation of the method used here is that it needs a number of land patches and landowners in most categories. Some counties (e.g., Perry and Pike counties) with limited forestland patches and owners, then, it is not necessary to use this approach.

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