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ORIGINAL ARTICLE

Linking landscape structures and ecosystem service value using multivariate regression analysis: a case study of the Chaohu Lake Basin, China

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Abstract Human activities have fragmented habitats around the world. In this case, understanding the links between landscape structures and ecosystem service value (ESV) is important because the provision of ecosystem services could be affected by landscape structural changes. The main objective of this study was to evaluate how the landscape structures affect multiple ESVs. This paper examined the influences of landscape structural changes on ESV by analyzing the changes in land use and landscape metrics in the Chaohu Lake Basin, China. Principal component analysis and multivariate regression were used to determine the relationships between landscape metrics and ESVs, while considering spatial autocorrelation. The results revealed significant differences in the ESV across the study area. Regulating services provided more than 58.8 % of the total ESV of the study area in 2007, followed by supporting, provisioning and cultural services. Patch sizes can significantly affect landscape metrics at the landscape level, and consequently, influence the relationships between landscape metrics and ESV. The fragmentation metrics were critical to the ESVs in the small patches. Moreover, the diversity, density, and connectivity metrics were important to the ESVs in the medium and great patches. In the large patches, the fragmentation, density, area and richness, and connectivity metrics were critical to multiple ESVs. The application of landscape metrics in landscape planning should receive particular attention because of the complexity of the impacts of landscape structural changes on the provision of ecosystem services are complex. These results could advance the understanding of the relationships between landscape structures and ecosystem services and guide landscape planning, management and restoration.

Keywords Landscape structure · Landscape metrics · Patch size · Spatial autocorrelation · Ecosystem service value · Land use

Introduction

Human activities, e.g., converting natural landscapes for human use, have fragmented habitats around the world (Foley et al. 2005; Burkhard et al. 2012; Su et al. 2014a; Mitchell et al. 2015; Rodriguez-Loinaz et al. 2015). Habitat fragmentation leads to isolated habitat patches and alters natural ecological processes (Fahrig 2003; Joly et al. 2003; Mitchell et al. 2013). These changes to landscape structures affect the material exchange and energy flow and impede the ability of ecosystems to provide their services (MA 2005) because all ecosystem services are to some extent related to the movement of organisms and materials across landscapes (Tscharntke et al. 2005; Le Maitre et al. 2007; Mitchell et al. 2014). The movement of organisms and materials largely depends on the landscape connectivity, which is defined as the degree to which the landscape facilitates or impedes movement among habitat patches (Taylor et al. 1993). Moreover, it has been recognized that

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landscape structures (composition, configuration and connectivity) play a major role in maintaining the biodiversity and the provision of ecosystem services (Taylor et al. 1993; Brosi et al. 2008; Bianchi et al. 2010; Kozak et al. 2011; Syrbe and Walz 2012; Palomo et al. 2014). Changes to landscape structures are likely to affect the ecosystem service values (ESVs), either positively or negatively (Mitchell et al. 2013). How different ecosystem services respond to landscape structures is poorly understood (Carpenter et al. 2006; Syrbe and Walz 2012; Mitchell et al. 2013), especially under different patch sizes. Accurate models of this response should be developed and used to guide landscape management planning and decision-making.

Numerous studies have investigated landscape structural changes and their impacts on ecosystems (Sun et al. 2007; Nassauer and Opdam 2008; Syrbe and Walz 2012; Jones et al. 2013; Palomo et al. 2014; Roces-Diaz et al. 2014; Mitchell et al. 2015). Most of these studies have reported environmental and ecological impacts of land use (Foley et al. 2005; Mitchell et al. 2013; Palomo et al. 2014). These impacts are complex and scale with the size of the affected area (Carpenter et al. 2006). For example, ecosystem degradation results from the synchronous reduction of multiple ESVs due to natural and human factors (Carpenter et al. 2006). Many measures have been employed to address the degradation of ecosystems and to maintain its different ecosystem services such as sustaining and restoring key habitat patches in landscapes on multiple scales (Opdam et al. 2006; Erős et al. 2011; Jones et al. 2013). Moreover, relationships between landscape structures and multiple ESVs should be analyzed further. A series of broad-scale experimental approaches and new technologies have been applied into practice, e.g., remote sensing, graph theory and network analysis (Bunn et al. 2000; Saura and Pascual-Hortal 2007; Spens et al. 2007; Nassauer and Opdam 2008; Sagarin and Pauchard 2010; Syrbe and Walz 2012; Gallardo et al. 2014).

Large-scale spatial data and modeled ESVs have enabled the linking of landscape structures and multiple ESVs over larger geographic areas. Landscape structures at different spatial scales have been characterized and mapped across the world (Luck and Wu 2002; Neel et al. 2004; Zimmermann et al. 2010; Liu et al. 2014). Many special tools are available for quantifying landscape structures at different spatial scales based on large amounts of land use data (Saura and Torne 2009; McGarigal et al. 2012). Furthermore, the responses of ecological processes and services to land cover and land use changes have been evaluated (Hu et al. 2008; Carreno et al. 2012; Lawler et al. 2014). However, landscape structural gradients and their relationships with landscape processes and ESVs have not been thoroughly considered (Jones et al. 2013). Some studies have investigated different ESVs responses to landscape structures, such as pollination, seed dispersal, and the provision of pest regulation services (Nathan et al. 2008; Margosian et al. 2009; Hadley and Betts 2012). These studies usually focused on linking landscape structures with one or two types of ESVs, e.g., provisioning services, but did not investigate links among various ESVs (Mitchell et al. 2013).

The main objective of this study was to evaluate how the landscape structures affect multiple ESVs. Multiple approaches, such as such as remote sensing (RS), global information systems (GIS), correlation analysis, principal component analysis and regression analysis, were used to facilitate the analysis. The Chaohu Lake Basin was used as a case study to: (1) analyze the changes in landscape structures across the Chaohu Lake Basin; (2) explore the relationships between landscape structures and multiple ESVs; and (3) address how different aspects of landscape structures affect multiple ESVs.

Materials and methods

Study area

The Chaohu Lake Basin is located in the central part of Anhui Province, eastern China (range from 116°23′49″ to 118°22′16″E and from 30°52′15″ to 32°07′59″N), with an estimated area of 1.41×10^8 hm^2 (Fig. 1). The Chaohu Lake Basin belongs to the drainage system in the lower reaches of the Yangtze River (Liu et al. 2012a; Wang et al. 2014). This area has a transitional monsoon climate between subtropical and warm temperate, with a mean annual rainfall of 1100 mm and the annual average temperature ranges between 15 and 16 °C (Xu et al. 2011; Huang et al. 2013; Jiang et al. 2014). There are eight main rivers centripetally distributed around Chaohu Lake, and only one river, the Yuxi River, links the lake to the Yangtze River (Fig. 1). The Chaohu Lake Basin is one of the most densely populated regions in Anhui Province, with a density of more than 760 persons per square kilometer in 2008 (Huang et al. 2013).

Data acquisition

In this study, the SRTM DEM data for the Chaohu Lake Basin with a pixel spatial resolution of 90 m were obtained from the internet (http://www.gscloud.cn/). A Landsat TM image from the 2007 was selected as the data source for landscape mapping after interpretation and supervised classification. The image was free of clouds and was obtained during the dry season. Based on the National

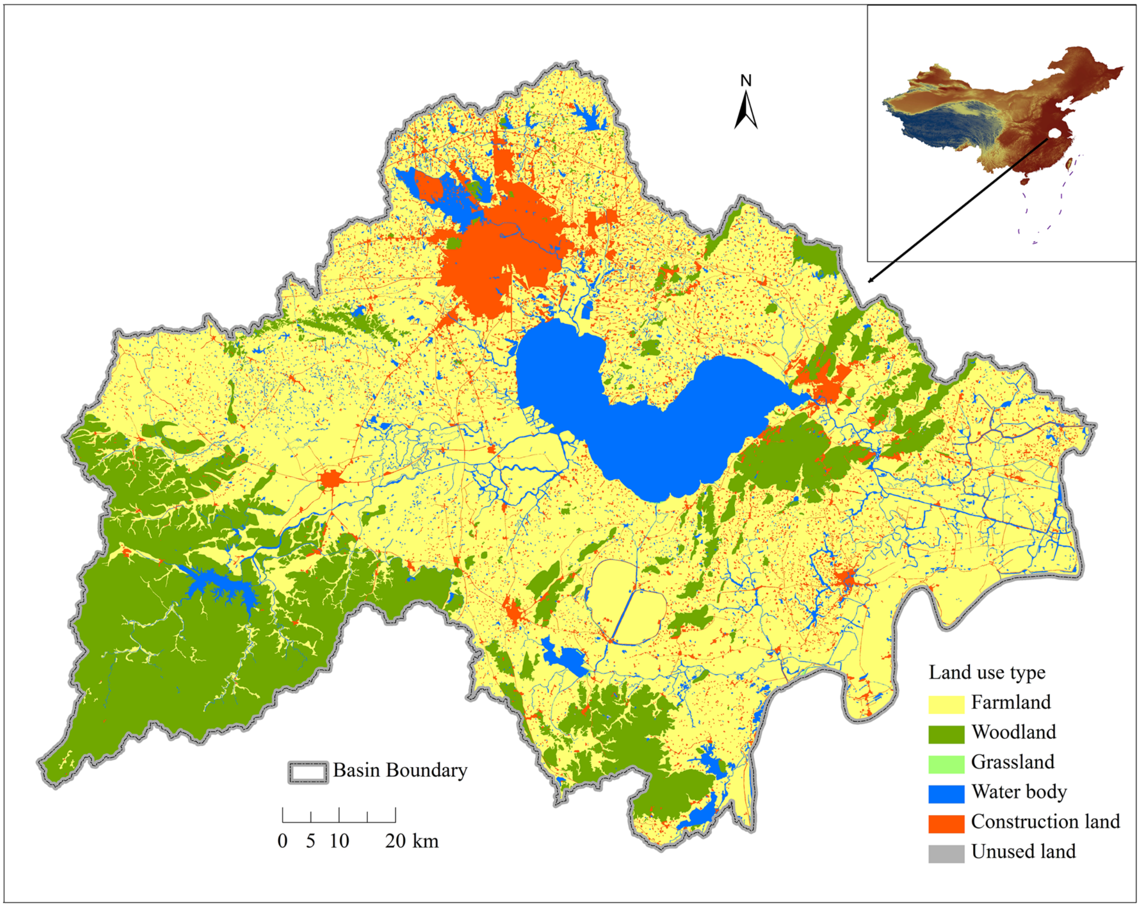

Fig. 1 Study area of the Chaohu Lake Basin and its land use types in the year 2007. The map of China is at the *top right*

1:250,000 Basic Terrain Database, ERDAS Imagine was used to adjust geometric correction of the Landsat images, and then the ArcGIS10.0 software was used to analyze the vector files from the ERDAS Imagine (Liu et al. 2011). The root mean squared error of the geometric rectification was less than one pixel. By comparing the current criteria for land use classification in China with the current land use conditions of the study area, the land use was classified into six types: farmland, woodland, grassland, water body, construction land, and unused land (Liu et al. 2012b; Zhang et al. 2015). Meanwhile, a field survey was conducted in April 2009 to evaluate the accuracy of the classification. The land use types at each survey point (59 points with GPS coordinates) were identified across the whole study area. The overall accuracy of the image classifications was 83.4 %. The land use maps of the study area in 2007 listed in Fig. 1.

Estimating ecosystem service values

The Costanza's ESVs assessment model was used to calculate the ESV (Costanza et al. 1997):

$$\mathrm{ESV}_{\mathrm{LU}} = \sum_{f} (A_k \times \mathrm{VC}_{kf}) \tag{1}$$

$$\mathrm{ESV}_{\mathrm{SF}} = \sum_{k} (A_k \times \mathrm{VC}_{kf}) \tag{2}$$

$$\mathrm{ESV}_{T} = \sum_{k} \sum_{f} (A_k \times \mathrm{VC}_{kf}) \tag{3}$$

where ESV_{LU}, ESV_{SF} and ESV_T refer to the ESV of land use type k, the value of ecosystem service type f and the total ESV, respectively. A_k is the area (hm^2) of land use type k and VC_{kf} is the value coefficient (Yuan/hm^2/year) for land use type k and ecosystem service type f.

The ecosystem services were classified into nine types according to Xie et al. (2003, 2008), as showed in Table 1. In this study, the benefit transfer method was used to estimate the ESV in the Chaohu Lake Basin based on the results of Liu et al. (2012b) and Zheng et al. (2010). To match the current criteria for land use classification in China, woodland is equivalent to forest, water area is equivalent to water body, and the ecosystem service value for construction land is zero. According to the modified coefficient which assigned to Anhui Province (Xie et al.

Table 1 Ecosystem service value coefficient of different land use types per unit area in the Chaohu Lake Basin (RMB Yuan/hm^2/year) (modified from Xie et al. 2003, 2005, 2008)

Ecosystem service	Farmland	Woodland	Grassland	Water body	Unused land	Construction land
Regulating services						
Gas regulation	378.3	2269.9	788.2	268.0	0	0
Climate regulation	509.7	2138.6	819.7	1082.4	0	0
Water supply	404.6	2149.0	798.7	9862.6	36.8	0
Waste treatment	730.4	903.8	693.6	7802.9	136.6	0
Supporting services						
Soil formation and protection	772.4	2112.3	1177.0	215.4	89.3	0
Biodiversity protection	536.0	2369.8	982.6	1802.3	210.2	0
Provisioning services						
Food production	525.4	173.4	225.9	278.5	10.5	0
Raw materials	204.9	1565.8	189.2	183.9	0	0
Cultural services						
Recreation and culture	89.3	1092.9	457.1	2333.0	126.1	0
Total value	4151.0	14,775.6	6132.0	23,829.0	609.5	0

2005), the EVS in the Chaohu Lake Basin can be calculated from the modified coefficient (1.17) multiplied by the value coefficient presented by Xie et al. (2003). The ESVs of different land use types per unit area in the Chaohu Lake Basin are listed in Table 1.

Selection and evaluation of landscape metrics

A large set of landscape metrics for the landscape composition and structural analysis was developed during the past decades (McGarigal and Marks 1995; Riitters et al. 1995; Hargis et al. 1998; Tinker et al. 1998). Researchers often use certain special landscape metrics because of their ability to indicate an ecological process (Leitão and Ahern 2002; Ribeiro and Lovett 2009; Su et al. 2011, 2012; McGarigal et al. 2012; Hepcan 2013; Liu et al. 2014). Four criteria for selecting the landscape metrics were proposed by Ribeiro and Lovett (2009) and Su et al. (2012, 2014b): (1) metrics were selected based on their ease of interpretation and their ability to cover both composition and configuration dimensions; (2) metrics should not be highly redundant; (3) comparability with previous landscape ecological studies, and (4) the ability to reflect the characteristics of landscape patterns in the study area. The procedure for indicator selection was similar to that for metric selection described in Su et al. (2014b).

Following these four criteria, we first collected a set of 16 landscape level metrics based on literature review. The Sixteen selected metrics are as follows: number of patches (NP), patch density (PD), the largest patch index (LPI), landscape division index (DIVISION), splitting index (SPLIT), patch richness (PR), patch richness density (PRD), contagion (CONTAG), aggregation index (AI), Shannon's diversity index (SHDI), Simpson's diversity index (SIDI), landscape shape index (LSI), total area (TA), total edge (TE), and edge density (ED). Moreover, the connectance index (CONNECT) was employed to calculate connectivity, which is defined as the number of functional links between patches of the same type, where each pair of patches is either connected or not connected based on a user-specified distance criterion (McGarigal et al. 2012). This criterion is either the Euclidean distance or the functional distance. In this paper, we set the distances to 100, 200, 400, 500, 800, 1000, 2000, 4000 and 8000 m to determine the effect of the distances on the CONNECT.

Human activities have resulted in an increase in the number of patches and a decrease in habitat area. It is well known that fragmentation, which affects landscape metrics, can be analyzed by calculating the areas and numbers of patches. Because patch size is region specific, four levels of patch sizes were classified to consider the areas of selected patches (modified from Liu et al. 2014), which are small patches ($\text{area} \leq 100\ \text{hm}^2$), medium patches ($100 < \text{area} \leq 1000\ \text{hm}^2$), large patches ($1000 < \text{area} \leq 2000\ \text{hm}^2$) and great patches ($\text{area} > 2000\ \text{hm}^2$). The changes in landscape structures related to patch area can be explained based on this classification of selected patches.

Data analysis

The landscape metrics were calculated using FRAGSTATS software (V4.1) with a cell size of 30 m to analyze landscape structural changes across the Chaohu Lake Basin (McGarigal et al. 2012). The land use data in a shape file format were converted to a raster format and input into FRAGSTATS 4.1 program to compute the landscape metrics for each subwatershed. The subwatersheds were introduced to visualize the spatial distributions of the ESVs in the study area. The subwatersheds were delineated based on the SRTM DEM data with a pixel spatial resolution of 90 m in the Chaohu Lake Basin, and the detailed methods are presented in Gao et al. (2011). Subwatersheds, which are areas dominated by similar ecosystems and environmental resources, are considered as the basic spatial units for the partitioning of ecoregions (Su et al. 2012). In total, 982 subwatersheds (average area of 14.4×10^4 hm^2) were delineated in the Chaohu Lake Basin. Using the subwatersheds as the basic unit, the spatial distribution of ESVs in the Chaohu Lake Basin in 2007 was exported. The results can provide assistance for the partitioning of ecoregions in the Chaohu Lake Basin.

Because many landscape metrics are frequently correlated, we used a principal components analysis (PCA) program to group the metrics into uncorrelated components that explained most of the variation in the original data (Tinker et al. 1998). The correlations between the landscape metrics and ESVs, including the nine types and the total ESV, were analyzed. Using the correlation matrix, PCA was used to distinguish the spatial heterogeneity between the landscape metrics and patch sizes in a table. In addition, the differences in the landscape metrics between different patch sizes were determined using one-way ANOVA followed by Bonferroni tests for pair-wise comparisons. The correlation analysis, PCA and ANOVA were performed using SPSS 20.0 (SPSS Inc., Chicago, IL).

The first five principal components were used as proxies for the landscape metrics for further multivariate regression analysis. Multivariate regression was conducted to explore the relationships between ESVs and the first five principal components (PCs) for the landscape metrics. In these models, the multiple ESVs were considered as dependent variables, and the first five PCs were considered as independent variables. The variables used in the regression analysis were first standardized (Zscore) and then analyzed. The multivariate regression was performed using the spatial computation software GeoDa (v.1.6.6, https://geodacenter.asu.edu/software), which is usually adopted to calculate weight matrices and analyze the spatial autocorrelation and regression (Anselin et al. 2006; Su et al. 2014a). Weight matrices based on rook-based contiguity were established to detect the spatial autocorrelation between ESVs. The classical linear regression model, the spatial lag model, and the spatial error model were selected on the basis of diagnostics for spatial autocorrelation (LeSage and Pace 2009). The data were analyzed at two different scales: (1) for the whole basin data set, and (2) each of the four patch sizes (small, medium, large and great) independently.

Results

Characteristics of ecosystem service values

This study analyzed the ESVs in the Chaohu Lake Basin using GIS and RS technology. The results showed that the total ESV of the Chaohu Lake Basin was 11.43 billion Yuan in 2007. The spatial distribution of the ESVs in the Chaohu Lake Basin during 2007 was shown in Fig. 2. The high ESVs were located in the middle and southwestern regions where there are large water body and woodland areas, and the low ESVs were distributed in the northern region of the study area, where cities and towns such as Hefei (the capital of Anhui province) are located.

This study also calculated nine ecosystem service types, which can be grouped into the following four categories: regulating, supporting, provisioning, and cultural services (Table 1). The boxplots of these ecosystem service types were shown in Fig. 3. Regulating services provided the major service values for the Chaohu Lake Basin in 2007, comprising more than 58.8 % of the total ESV, followed by supporting, provisioning and cultural services which accounted for 24.1, 10.6 and 6.5 %, respectively (Fig. 4a). Moreover, water supply (WAT) was the highest ESV, comprising 21.2 % of the total ESV in the Chaohu Lake Basin, followed by waste treatment (WAS; 7.7 %), biodiversity protection (BIO; 12.5 %), soil formation and protection (SOI; 11.6 %), climate regulation (CLI; 10.8 %), gas regulation (GAS; 9.2 %), recreation and culture (REC; 6.5 %), raw materials (RAW; 5.9 %) and food production (FOO; 4.7 %) (Fig. 4b).

In the Chaohu Lake Basin, the Moran statistics (Moran's I) for all types of ESVs, except climate regulation, were highly significant ($P = 0.001$, Table S1), suggesting a problem with spatial autocorrelation. Similar results can be observed for the medium patches and large patches. Conversely, for all ESVs in the small patches and most ESVs in the great patches, the Moran's I was not significant, suggesting that there were no problems with spatial autocorrelation. ($P > 0.01$, Table S1). Base on the spatial regression decision process developed by Anselin et al. (2006), the classical linear regressive model, the spatial lag model, and the spatial error model were used to determine the relationships between the multiple ESVs and the first five PCs for the landscape metrics.

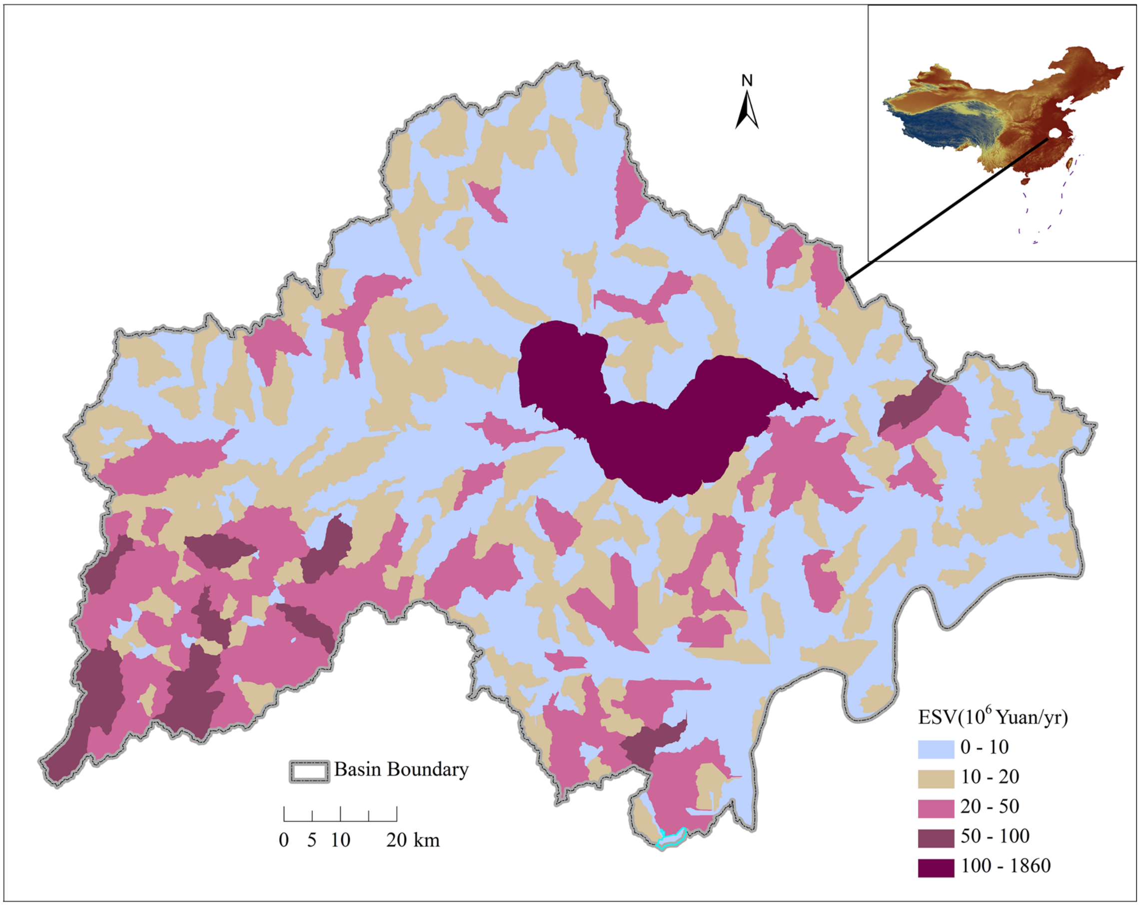

Fig. 2 Spatial distribution of the ecosystem service values (ESVs, 10^6 Yuan/year) for 982 subwatersheds in the Chaohu Lake Basin during 2007

Characteristics of landscape metrics

Most of the landscape metrics increased as the patch sizes increased, including NP, SPLIT, DIVISION, PR, TA, TE, LSI and SHDI (Fig. 5a, b, d). However, some metrics decreased with increasing patch size, including PD, LPI, ED, PRD and AI (Fig. 5a–c). In addition, the means of CONTAG increased as the patch size increased from small to medium and then plateaued as the patch size increased further to Great (Fig. 5e). By contrast, the means of CONNECT decreased with increasing patch size when the threshold distances were set to 100, 200, 400, 800 and 1000 m but increased initially and then decreased as the patch size increased from small to great patches for threshold distances of 2000, 4000 and 8000 m (Fig. 5f). There were significant differences in the landscape metrics between the four patch sizes ($P < 0.05$; Fig. 5), except for SHDI ($F = 2.68$, $P = 0.05$) and SIDI ($F = 1.23$, $P = 0.30$).

Based on the PCA performed using SPSS, the first five principal components together explained approximately 85 % of the variation in the 16 landscape metrics (Table 2). The first principal component (PC1) was positively related to SIDI, SHDI, DIVISION, SPLIT and ED and was negatively correlated with LPI alone, suggesting that this component mainly represented the diversity metrics. The second principal component (PC2) was positively related to NP, TE and LSI, and was negatively correlated with AI alone, suggesting that this component mainly represented the fragmentation metrics. The third principal component (PC3) was positively related to PD and PRD, suggesting that this component mainly represented the density metrics. The fourth principal component (PC4) was positively related to TA and PR, suggesting that this component mainly represented the area and richness metrics. The fifth principal component (PC5) was positively related to CONTAG and CONNECT, suggesting that this component mainly represented the connectivity metrics.

Relationships between landscape metrics and ecosystem service values

There were significant relationships between all of the landscape metrics (except CONTAG) and the ESVs

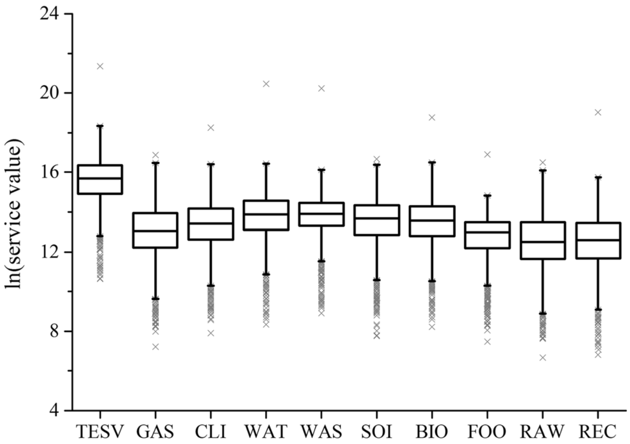

Fig. 3 *Boxplots* of the ecosystem service values in the Chaohu Lake Basin based on 982 subwatersheds. The ecosystem service values were transformed to natural logarithms to compress the range for display on the *y* axis. *TESV* total ecosystem service value, *GAS* gas regulation, *CLI* climate regulation, *WAT* water supply, *WAS* waste treatment, *SOI* soil formation and protection, *BIO* biodiversity protection, *FOO* food production, *RAW* raw material and *REC* recreation and culture. The *top* and *bottom lines* of the *boxplots* are the maximum and minimum values, respectively. The *upper*, *middle* and *lower* boundaries of the *rectangles* are the 75th, 50th and 25th percentile values, respectively, and '×' represents outliers

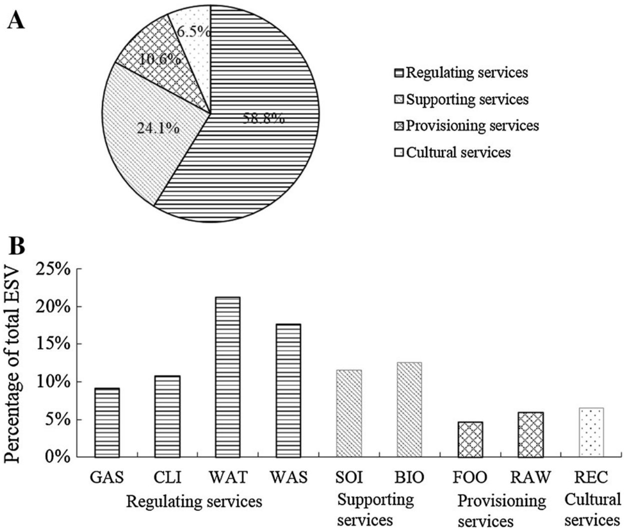

Fig. 4 Percentage of different types of ecosystem service values in the Chaohu Lake Basin: **a** for overall ecosystem service categories, i.e., regulating, supporting, provisional, and cultural services; **b** for nine specific ecosystem services. *GAS* gas regulation, *CLI* climate regulation, *WAT* water supply, *WAS* waste treatment, *SOI* soil formation and protection, *BIO* biodiversity protection, *FOO* food production, *RAW* raw material and *REC* recreation and culture

(Table 3). There were significant positive correlations between most of the landscape metrics and the ESVs ($P < 0.01$), and these metrics contained TA, NP, TE, LSI, DIVISION, SPLIT, PR, SHDI and SIDI. On the other hand, six metrics were significantly negatively correlated with the total ESV ($P < 0.01$), i.e., PD, LPI, ED, CONNECT, PRD and AI. Similarly, there were significant relationships (positive or negative) between most of the landscape metrics and the nine types of ESVs ($P < 0.01$). Although some correlation coefficients were quite low, such as those for LPI vs. BIO ($R^2 = -0.095$, $P < 0.01$) and LPI vs. GAS ($R^2 = -0.065$, $P < 0.05$), these values were still significant due to the relatively large sample size ($n = 982$).

The analysis of the relationships between the multiple ESVs and the first five PCs for the landscape metrics produced some interesting results. There were significant relationships between three types of ESVs (GAS, FOO and RAW) and 4 of the five PCs (Table 4). Seven other types of ESVs were significantly related to all five PCs (Table 4). Soil formation and protection (SOI) showed a significant increasing trend with the first five PCs as the landscape metrics decreased (negative slopes; Table 4). Similar results were found when GAS and FOO were considered (Table 4). An interesting result is that the density metrics (PD and PRD) and the area and richness metrics (TA and PR) showed the same decreasing trends (Table 4), which is somewhat contradictory because the density metrics showed significant negative relationships with multiple ESVs, whereas the area and richness metrics showed significant positive relationships (Table 3). In contrast, ESV, WAT, WAS and REC showed significant positive relationships with the first five PCs for landscape metrics (Table 4). CLI showed significant positive relationships with PC1 and PC5 and negative relationships with PC2, PC3 and PC4. BIO showed significant positive relationships with PC1, PC2 and PC5 and negative relationships with PC3 and PC4. Finally, FOO showed significant positive relationships with PC3 and PC4, and negative relationships with PC1 and PC2 (Table 4).

As shown in Table 4, the ESV was significantly correlated with the five principal components for the landscape metrics at different patch sizes. All multiple ESVs except SOI and FOO were significant relationships with one out of the five PCs in the small patches (Table 4). Many ESVs (including ESV, CLI, SOI, BIO, FOO) increased when PC2 exhibited a significant decreasing trend in the small patches (negative slopes; Table 4). Most types of the ESVs showed significant relationships with PC1, PC3, PC4 and PC5 in the medium patches (Table 4). In addition, most types of the ESVs showed significant relationships with PC2, PC3, PC4 and PC5 in the large patches (Table 4). Almost all types of the ESVs showed significant relationships with PC1, PC3 and PC5 in the great patches (Table 4). The fragmentation metrics were critical to the ESVs in the small patches, and the density metrics and connectivity metrics were important for ESVs in the other three patch sizes.

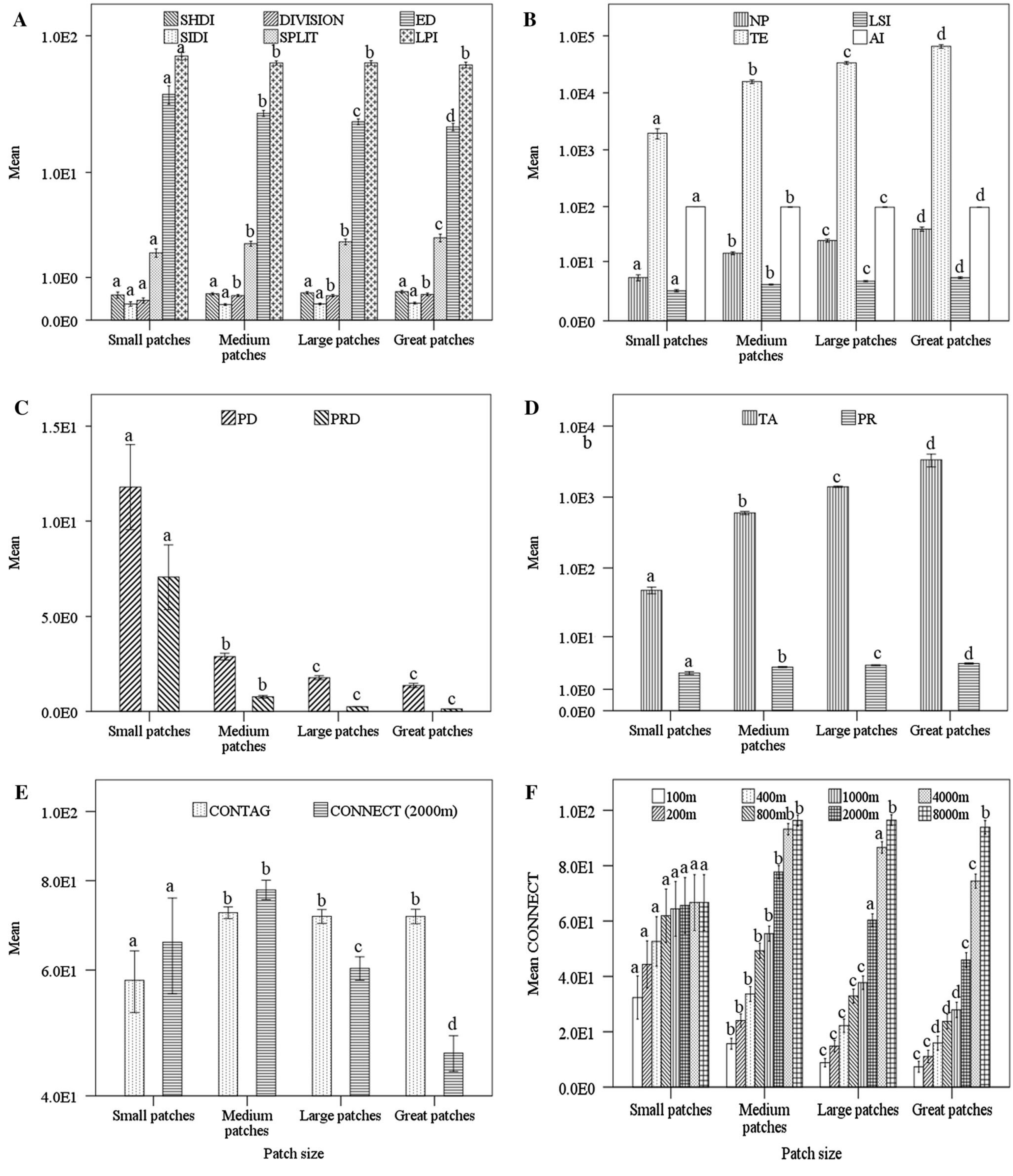

Fig. 5 Landscape metrics for the four patch sizes (*error bars* 95 % confidence intervals). **a** Diversity metrics (SIDI, SHDI, DIVISION, SPLIT, ED, LPI); **b** fragmentation metrics (NP, TE, LSI, AI); **c** density metrics (PD and PRD); **d** area and richness metrics (TA and PR); **e** connectivity metrics (CONTAG and CONNECT) for a threshold distance of 2000 m; **f** CONNECT for threshold distances of 100, 200, 400, 500, 800, 1000, 2000, 4000 and 8000 m. All the metrics are calculated using the FRAGSTATS 4.1 program at the landscape level. The units of TA, TE, ED and PRD are hectares, meters, meters per hectare and number per 100 hectares, respectively. PD, LPI, CONTAG, CONNECT and AI have the same unit (%), and the remaining metrics are unitless

Table 2 Principal component loadings for the landscape metrics used in the landscape level analysis

Index	Component				
	PC1	PC2	PC3	PC4	PC5
① SHDI	**0.92**	0.07	0.08	0.29	−0.05
① SIDI	**0.92**	0.01	0.09	0.26	−0.11
① DIVISION	**0.87**	0.33	−0.02	−0.19	0.00
① SPLIT	**0.72**	0.40	−0.06	−0.28	−0.13
① ED	**0.61**	0.25	0.50	−0.25	0.13
① LPI	**−0.86**	−0.30	0.04	0.22	0.05
② NP	0.07	**0.90**	−0.03	0.25	0.04
② TE	0.20	**0.89**	−0.14	0.23	−0.05
② LSI	0.40	**0.88**	−0.08	0.03	0.03
② AI	−0.33	**−0.84**	0.08	0.01	−0.02
③ PD	0.07	−0.09	**0.95**	−0.11	0.01
③ PRD	−0.04	−0.18	**0.91**	0.01	−0.12
④ TA	−0.12	0.31	−0.10	**0.63**	−0.06
④ PR	0.48	0.27	−0.11	**0.58**	0.44
⑤ CONTAG	−0.36	0.06	−0.07	0.06	**0.85**
⑤ CONNECT	0.37	−0.50	−0.01	−0.24	**0.53**
Eigenvalue	6.37	3.14	1.72	1.27	1.02
Cum. Var./%	39.78	59.39	70.11	78.05	84.4

Bold indicates the highest loadings for each index

① = diversity metrics, ② = fragmentation metrics, ③ = density metrics, ④ = area and richness metrics, ⑤ = connectivity metrics

Discussion

Landscape structures affect the provision of ecosystem services

Recent studies have reported the interactions between landscape structures and ESVs at the landscape level (Frank et al. 2012; Su et al. 2012; Mitchell et al. 2015). A combined assessment of the relationships between the landscape metrics and multiple ESVs can improve the understanding of how landscape structure contributes to the provision of ecosystem services (Frank et al. 2012). The relationships between the landscape metrics and ESVs can offer some immediate impressions. Landscape diversity metrics consistently show positive relationships with biodiversity and food production (Nagendra 2002; Shrestha et al. 2010). However, our results appeared to contradict these statements. In our study, the quantitative interactions between the five types of the landscape metrics and multiple ESVs were identified based on multivariate regression analysis. Our results indicated that the diversity metrics (PC1) revealed positive impacts on the provision of the ESVs, such as the total ESV, climate regulation, water supply, waste treatment, biodiversity protection, recreation and culture at the subwatershed scale in the Chaohu Lake Basin, and negative relationships with gas regulation, soil formation and protection, food production, and raw materials (Table 4). The landscape diversity was not high in the study area, and increases in the diversity metrics (PC1) resulted from increases in fragmented patches with higher coefficients for calculating the ESV (e.g., water bodies; Table 1). Different relationships between PC1 and multiple ESVs were found for the four patch sizes in this paper (Table 4). The driving force for the increases in the diversity metrics should account for these differences (Su et al. 2012).

Fragmentation can lead to a decline in the ESVs because this process can destroy corridors for biotic and abiotic movement, limit the movement of soil microorganisms, cause a decline in habitat quality and decrease the water exchanges (Li et al. 2011; Shrestha et al. 2012; Su et al. 2012; Qi et al. 2014). Our results, which appeared to contradict these statements, indicated that the fragmentation metrics (PC2) had positive impacts on the provision of the ESVs, such as the total ESV, water supply, waste treatment, biodiversity protection, recreation and culture at the subwatershed scale, and had negative relationships with gas regulation, climate regulation, soil formation and protection, and raw materials (Table 4). An increase in fragmentation of water body patches may account for this result in the study area.

The density metrics (PD) have been reported to have negative relationships with waste treatment and biodiversity protection (Su et al. 2012), but our results seemed to be inconsistent with this finding. For example, our results indicated that the density metrics (PC3) revealed positive impacts on the provision of the ESVs, such as the total ESV, water supply, waste treatment, food production, recreation and culture at the subwatershed scale, but negative relationships with gas regulation, climate regulation, soil formation and protection, biodiversity protection, and raw materials (Table 4). Similar results were found between the area and richness metrics (PC4) and the multiple ESVs (Table 4).

The connectivity metrics (PC5) had positive impacts on the provision of the ESVs, such as the total ESV, climate regulation, water supply, waste treatment, biodiversity protection, recreation and culture at the subwatershed scale, but negative relationships with soil formation and protection and food production (Table 4). The reason for these relationships may be that fragmentation can lead to a greater number of small patches, which may cause the increases in CONNECT (Su et al. 2012). Landscape heterogeneity and habitat connectivity were criteria for the behavior of metapopulations and for cultural services (Syrbe and Walz 2012). To assess the effect of distance on

Table 3 The relationships between landscape metrics and ecosystem service values (Spearman correlation, $n = 982$)

Index	Regulating services				Supporting services		Provisioning services		Cultural services	TESV
	GAS	CLI	WAT	WAS	SOI	BIO	FOO	RAW	REC	
SHDI	0.17**	0.17**	0.26**	0.18**	0.10**	0.18**	0.04	0.19**	0.30**	0.19**
SIDI	0.14**	0.14**	0.24**	−0.15**	0.07*	0.16**	−0.01	0.16**	0.28**	0.16**
DIVISION	0.07*	0.09**	0.21**	0.21**	0.05	0.10**	0.14**	0.07*	0.19**	0.13**
SPLIT	0.07*	0.09**	0.21**	0.21**	0.05	0.10**	0.14**	0.07*	0.19**	0.13**
ED	−0.32**	−0.31**	−0.18**	−0.13**	−0.32**	−0.30**	−0.13**	−0.32**	−0.22**	−0.27**
LPI	−0.07*	−0.08*	−0.20**	−0.19**	−0.04	−0.10**	−0.11**	−0.07*	−0.19**	−0.12**
NP	0.37**	0.40**	0.41**	0.59**	0.44**	0.40**	0.76**	0.36**	0.34**	0.43**
TE	0.61**	0.65**	0.67**	0.78**	0.67**	0.65**	0.83**	0.60**	0.61**	0.68**
LSI	0.35**	0.39**	0.47**	0.60**	0.40**	0.40**	0.63**	0.35**	0.41**	0.44**
AI	−0.34**	−0.37**	−0.45**	−0.56**	−0.38**	−0.38**	−0.59**	−0.33**	−0.38**	−0.41**
PD	−0.70**	−0.70**	−0.62**	−0.53**	−0.68**	−0.70**	−0.42**	−0.70**	−0.65**	−0.68**
PRD	−0.79**	−0.82**	−0.77**	−0.84**	−0.85**	−0.82**	−0.85**	−0.77**	−0.73**	−0.84**
TA	0.84**	0.87**	0.81**	0.89**	0.893*	0.87**	0.90**	0.82**	0.78**	0.88**
PR	0.47**	0.46**	0.40**	0.40**	0.44**	0.46**	0.42**	0.48**	0.44**	0.44**
CONTAG	−0.01	−0.02	−0.15**	−0.05	0.05	−0.04	0.15**	−0.02	−0.17**	−0.06
CONNECT[a]	−0.37**	−0.40**	−0.38**	−0.49**	−0.43**	−0.40**	−0.58**	−0.35**	−0.33**	−0.42**

Logarithmic transformation have been carried out on all types of ESV before correlation analyses

NP number of patches, *PD* patch density, *LPI* largest patch index, *DIVISION* landscape division index, *SPLIT* splitting index, *PR* patch richness, *PRD* patch richness density, *TA* total area, *TE* total edge, *ED* edge density, *LSI* landscape shape index, *CONTAG* contagion index, *AI* aggregation index, *SHDI* Shannon's diversity index, *SIDI* Simpson's diversity index, *CONNECT* connectance index, *GAS* gas regulation, *CLI* climate regulation, *WAT* water supply, *WAS* waste treatment, *SOI* soil formation and protection, *BIO* biodiversity protection, *FOO* food production, *RAW* raw material, *REC* recreation and culture, *TESV* total ecosystem service value

* Correlation is significant at the 0.05 level (2-tailed)

** Correlation is significant at the 0.01 level (2-tailed)

[a] The threshold distance is set to 2000 m

CONNECT, eight distances were selected (Fig. 5d), and the relationships between CONNECT and ESVs at different threshold distances were presented in Table 5. The values of CONNECTs based on eight distances were significantly negative correlation with all types of the ESVs ($P < 0.01$, Table 5). The highest correlation coefficient between CONNECT and the ESVs occurred when the threshold distance was set to 2000 m, which indicated that patches within a 2000 m radius were of crucial importance to the provision of ESVs.

Many factors may account for these differences. The number of landscape metrics used in the regression may lead to different results. In addition, principal components, not merely single metrics, were used to quantify the interactions between the landscape structures and multiple ESVs, which may contribute to the inconsistency with previous reports (Nagendra 2002; Shrestha et al. 2010, 2012; Li et al. 2011; Su et al. 2012; Qi et al. 2014). Scale could be another critical reason, as the landscape metrics were different and changed with scale (Su et al. 2011).

Implications for landscape planning

Landscape planners require scientific guidance to address environmental problems in the context of urbanization and land use change (Koschke et al. 2012; Su et al. 2012). They often rely on landscape metrics, and reliable guidance can be obtained by linking landscape metrics and ecological problems. For example, the degradation or disturbance of the ecosystem services can be detected by the changes in landscape metrics (Frank et al. 2012). Because landscape structural changes can indicate whether the objectives of landscape planning are realized (Su et al. 2012). Therefore, the interactions between landscape structure and ESVs can provide information on landscape planning in the Chaohu Lake Basin.

Landscape metrics can reveal the economic value of landscapes according to interactions with ESVs (Wainger et al. 2010). For example, in the small patches, the fragmentation metrics (PC2) were critical factors for the provision of ESVs (Table 4). Fragmentation metrics increased as temperature, soil erosion, biodiversity, and food

Table 4 Summary of the multiple regression models for the ecosystem service values and the five principal components for the landscape metrics of the Chaohu Lake Basin

Dependent	Patch size (*n*)	Standardized coefficients regression	*P*	Model
Gas regulation	Small (87)	$0.16 \times PC1$	0.001	a
	Medium (356)	$4.86 \times PC1 - 4.94 \times PC3 - 0.25 \times PC4 + 0.76 \times PC5$	0.001	c
	Large (317)	$-153.07 \times PC2 - 151.99 \times PC3 - 5.80 \times PC4 + 2.77 \times PC5$	0.001	c
	Great (222)	$-234.57 \times PC1 - 792.83 \times PC2 - 548.92 \times PC3 - 15.36 \times PC4 - 13.34 \times PC5$	0.001	b
	All (982)	$-0.828 \times PC1 - 43.67 \times PC2 - 34.74 \times PC3 - 1.04 \times PC4$	0.006	c
Climate regulation	Small (87)	$-0.15 \times PC2$	0.001	a
	Medium (356)	$32.54 \times PC1 + 33.46 \times PC2 +4.04 \times PC5$	0.001	c
	Large (317)	$-73.65 \times PC2 - 73.12 \times PC3 - 2.49 \times PC4 + 1.61 \times PC5$	0.001	c
	Great (222)	$-206.21 \times PC2 - 204.58 \times PC3 - 4.79 \times PC4$	0.001	b
	All (982)	$13.97 \times PC1 - 20.04 \times PC2 - 34.14 \times PC3 - 1.29 \times PC4 + 2.15 \times PC5$	0.001	a
Water supply	Small (87)	$0.07 \times PC3$	0.001	a
	Medium (356)	$2.45 \times PC1 - 2.48 \times PC3 - 0.17 \times PC4 + 0.36 \times PC5$	0.001	c
	Large (317)	$-18.25 \times PC2 - 18.12 \times PC3 - 0.89 \times PC4 + 0.47 \times PC5$	0.001	c
	Great (222)	$161.49 \times PC1 + 371.29 \times PC2 + 204.86 \times PC3 + 8.00 \times PC4 + 8.23 \times PC5$	0.001	a
	All (982)	$53.33 \times PC1 + 84.37 \times PC2 + 29.53 \times PC3 + 1.36 \times PC4 + 3.64 \times PC5$	0.001	b
Waste treatment	Small (87)	$0.07 \times PC3$	0.001	a
	Medium (356)	$-3.56 \times PC2 - 3.52 \times PC3 - 0.20 \times PC4 + 0.1.5 \times PC5$	0.006	b
	Large (317)	$3.83 \times PC1 - 3.87 \times PC3 - 0.28 \times PC4 + 0.50 \times PC5$	0.003	a
	Great (222)	$167.44 \times PC1 + 408.35 \times PC2 + 235.62 \times PC3 + 8.93 \times PC4 \pm 8.50 \times PC5$	0.001	a
	All (982)	$51.98 \times PC1 + 87.53 \times PC2 + 34.06 \times PC3 + 1.55 \times PC4 + 3.49 \times PC5$	0.001	b
Soil formation and protection	Small (87)	$-0.38 \times PC2 + 0.2 \times PC4 + 1.16 \times PC5$	0.02	a
	Medium (356)	$23.77 \times PC1 + 24.41 \times PC2 + 3.72 \times PC5$	0.001	c
	Large (317)	$-110.24 \times PC2 - 109.42 \times PC3 - 4.03 \times PC4 + 2.53 \times PC5$	0.001	c
	Great (222)	$-302.79 \times PC1 - 887.81 \times PC2 - 574.07 \times PC3 - 17.54 \times PC4 - 15.91 \times PC5$	0.001	b
	All (982)	$-68.21 \times PC1 - 167.85 \times PC2 - 97.22 \times PC3 - 3.35 \times PC4 - 2.94 \times PC5$	0.001	b
Biodiversity protection	Small (87)	$-0.17 \times PC2$	0.001	a
	Medium (356)	$9.54 \times PC1 - 9.72 \times PC3 - 0.43 \times PC4 + 1.42 \times PC5$	0.001	c
	Large (317)	$-54.90 \times PC2 - 54.50 \times PC3 - 2.27 \times PC4 + 1.26 \times PC5$	0.001	c
	Great (222)	$47.32 \times PC1 - 47.93 \times PC3 + 2.43 \times PC5$	0.001	a
	All (982)	$28.49 \times PC1 + 16.08 \times PC2 - 13.03 \times PC3 - 0.39 \times PC4 + 2.73 \times PC5$	0.012	b
Food production	Small (87)	$-0.45 \times PC2 + 0.25 \times PC4 + 1.50 \times PC5$	0.009	a
	Medium (356)	$-14.20 \times PC1 + 14.62 \times PC3 + 1.05 \times PC4 - 0.43 \times PC5$	0.020	a
	Large (317)	$-28.69 \times PC1 + 29.29 \times PC3 + 1.47 \times PC4 - 1.54 \times PC5$	0.001	b
	Great (222)	$169.60 \times PC2 + 168.52 \times PC3 + 5.55 \times PC4$	0.001	a
	All (982)	$-26.53 \times PC1 + 27.14 \times PC2 + 1.25 \times PC3 - 15.36 \times PC4 - 1.20 \times PC5$	0.001	b

Table 4 continued

Dependent	Patch size (*n*)	Standardized coefficients regression	*P*	Model
Raw material	Small (87)	$0.14 \times PC1$	0.01	a
	Medium (356)	$34.07 \times PC1 + 35.05 \times PC2 + 4.09 \times PC5$	0.001	c
	Large (317)	$-161.05 \times PC2 - 159.93 \times PC3 - 6.13 \times PC4 + 2.81 \times PC5$	0.001	c
	Great (222)	$-222.76 \times PC1 - 774.70 \times PC2 - 542.89 \times PC3 - 14.91 \times PC4 - 12.94 \times PC5$	0.001	b
	All (982)	$-6.66 \times PC1 - 41.38 \times PC2 - 34.13 \times PC3 - 0.93 \times PC4$	0.015	c
Recreation and culture	Small (87)	$0.07 \times PC3$	0.001	a
	Medium (356)	$4.86 \times PC1 - 4.95 \times PC3 - 0.28 \times PC4 + 0.65 \times PC5$	0.001	c
	Large (317)	$-31.03 \times PC2 - 30.82 \times PC3 - 1.41 \times PC4 + 0.72 \times PC5$	0.001	c
	Great (222)	$135.90 \times PC1 + 274.60 \times PC2 + 134.90 \times PC3 + 5.73 \times PC4 + 7.04 \times PC5$	0.001	a
	All (982)	$50.64 \times PC1 + 72.23 \times PC2 + 19.22 \times PC3 + 0.93 \times PC4 + 3.63 \times PC5$	0.001	b
Total ecosystem service value	Small (87)	$-0.10 \times PC2$	0.001	a
	Medium (356)	$4.86 \times PC1 - 4.94 \times PC3 - 0.25 \times PC4 + 0.76 \times PC5$	0.001	c
	Large (317)	$-0.003 \times PC2 - 0.006 \times PC3 - 0.004 \times PC4 + 0.001 \times PC5$	0.001	c
	Great (222)	$108.86 \times PC1 + 211.08 \times PC2 + 99.28 \times PC3 + 4.41 \times PC4 + 5.79 \times PC5$	0.001	a
	All (982)	$42.66 \times PC1 + 57.84 \times PC2 + 14.04 \times PC3 + 0.72 \times PC4 + 3.22 \times PC5$	0.001	b

All data were standardized (*Z* score)

n in (brackets) indicates the number of samples

Patch size: small patches (area $\leq$ 100 hm^2), medium patches (100 $<$ area $\leq$ 1000 hm^2), large patches (1000 $<$ area $\leq$ 2000 hm^2), great patches (area $>$ 2000 hm^2)

a is classical linear regressive model

b is spatial lag models: rho not listed

c is spatial error models: lambda not listed

Table 5 The relationships between CONNECT and ecosystem service values at different threshold distances (Spearman correlation, $n = 982$)

Threshold distance/m	Regulating services				Supporting services		Provisioning services		Cultural services	TESV
	GAS	CLI	WAT	WAS	SOI	BIO	FOO	RAW	REC	
100	−0.21**	−0.22**	−0.17**	−0.22**	−0.24**	−0.21**	−0.28**	−0.20**	−0.16**	−0.21**
200	−0.24**	−0.25**	−0.20**	−0.27**	−0.28**	−0.24**	−0.39**	−0.23**	−0.17**	−0.24**
400	−0.25**	−0.27**	−0.22**	−0.33**	−0.30**	−0.26**	−0.46**	−0.24**	−0.18**	−0.27**
800	−0.33**	−0.35**	−0.30**	−0.42**	−0.38**	−0.34**	−0.55**	−0.31**	−0.26**	−0.35**
1000	−0.33**	−0.36**	−0.32**	−0.44**	−0.39**	−0.35**	−0.57**	−0.32**	−0.27**	−0.37**
2000	−0.37**	−0.40**	−0.38**	−0.49**	−0.43**	−0.40**	−0.58**	−0.35**	−0.33**	−0.42**
4000	−0.33**	−0.37**	−0.38**	−0.49**	−0.39**	−0.37**	−0.54**	−0.32**	−0.32**	−0.40**
8000	−0.20**	−0.22**	−0.20**	−0.24**	−0.24**	−0.22**	−0.24**	−0.19**	−0.17**	−0.23**

** Correlation is significant at the 0.01 level (2-tailed)

production decreased because corridors for biotic and abiotic movement could be destroyed, and their movement would then be limited across the region. Fragmentation that creates small patches should receive special attention during landscape planning. In addition, there were positive relationships between the diversity and connectivity metrics (PC1 and PC5) and almost all of the multiple ESVs in the medium patches. In contrast, PC3 and PC4 showed negative relationships with five ninths of the multiple ESVs (Table 4). In the large patches, PC2, PC3, and PC4 increased with decrease in almost all of the ESVs, and PC5 was positively related with all of the multiple ESVs except food production (Table 4). More than half of ESVs were negatively related with PC1 and PC3, and PC5 showed positive relationships with four ninths of multiple ESVs in great patches (Table 4).

An important note for landscape planning was that, without the consideration of landscape metrics for different patch sizes, the objectives of landscape planning (e.g., revealing the potential economic values of the landscape) would be difficult to achieve. The evaluation of ESVs must be easy to perform and inexpensive (Su et al. 2012). This paper provided a method to meet both of these requirements. The ESVs were easily calculated based on the benefit transfer method (Costanza et al. 1997). Multivariate regression was used to detect the interactions between landscape structures and ESVs using different patch sizes. Using this information, planners can better understand how landscape structure contributes to the provision of ecosystem services and assess the subsequent economic loss in terms of declines in the values of ecosystem services. These interactions could be useful for landscape planning by promoting sustainable development and maintaining the service values of landscapes.

Limitations and further research

The landscape metrics were selected according to criteria proposed by Ribeiro and Lovett (2009) and Su et al. (2012). These landscape metrics were used to detect the changes in landscape structure at the subwatershed scale. A PCA program was used to group the metrics into uncorrelated components that explained most of the variation in the landscape metrics. Multivariate regression was used to explore the relationships between the ESVs and the principal components for the landscape metrics, while considering spatial autocorrelation. However, some issues remain unaddressed, such as the quality of the data source, the selection of landscape metrics, and the number of samples used in the regression analysis (Su et al. 2012).

The evaluation model of Costanza et al. (1997) was employed to calculate ESVs by multiplying the ecosystem value coefficients by the areas of the different land use types (Li et al. 2010; Su et al. 2012). The accuracy of the estimation results of this model may be not sufficient, but the adjusted value coefficients were multiplied by the modified coefficient recommended by Xie et al. (2003). Although the accuracy of the ecosystem value coefficients can affect the results, the estimates of the temporal change of ESVs were shown to be reliable using a time series analysis (Li et al. 2010; Su et al. 2012; Zhang et al. 2015). To verify this description, we increased or decreased adjusted the ecosystem value coefficients by 50 % and calculated the estimated changes of the nine ESVs and the total ESV (Zhang et al. 2015). The assessed ESVs were relatively inelastic with respect to changes in the coefficient of sensitivity, which indicated that the estimation of ESVs in the study area was robust and the results were relatively reliable.

Only the land use data for the year 2007 were used to assess how changes in landscape structure affect the provision of ecosystem services. A longer period, especially one including more recent years, should be considered in additional studies. Certain landscape metrics at the class level for a specific land use, such as forest, water bodies or woodlands, should be considered in the analysis of the interactions between landscape structure and ESVs. Furthermore, newly developed metrics including topological network measures should be used to explain how different aspects of connectivity affect the provision of ecosystem services.

Conclusions

This paper analyzed the characteristics of ESVs and landscape structures based on land use in the Chaohu Lake Basin. Subwatersheds were used as the basic spatial unit to estimate the ESVs and calculate the landscape metrics. The high ESVs were located in the middle and southwestern region of the study area, whereas the low ESV was distributed in the north. Regulating services provided the greatest service values for the Chaohu Lake Basin in 2007, followed by supporting, provisioning and cultural services. Patch sizes can significantly affect landscape metrics at the landscape level. Most landscape metrics increased with increasing patch size. Based on PCA, the first five principal components were used to explain the variation in the 16 landscape metrics. A multivariate regression was used to detect the interactions between landscape structures and ESVs for different patch sizes. Fragmentation metrics (PC2) were critical to ESVs in the small patches. Moreover, the diversity metrics (PC1), the density metrics (PC3) and the connectivity metrics (PC5) were important to ESVs in the medium and great patches. In the large patches, PC2, PC3, PC4 and PC5 were critical to multiple ESVs.

The evaluation of ESVs alone is insufficient for the application of the interactions between landscape structures and ESVs to guide landscape planning; the effects of scale on these relationships. It is necessary to assess the changes in multiple ESVs associated with the dynamics of landscape structures caused by different patch sizes. This analysis could promote an understanding of the ecological significance of the metrics used in landscape planning. It is important to note that the objectives of landscape planning are difficult to achieve without the consideration of landscape metrics for different patch sizes.

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