Landscape ecological approach to the ecological significance of cultural heritage sites

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Abstract: Although cultural heritage sites are extensively studied, their land use implications are widely unexplored. We therefore employed a landscape ecology approach to investigate cultural heritage sites and their ecological impacts in the Beijing region. This study assesses (1) the effects of cultural heritage sites on surrounding land use patterns at multiple scales and (2) the influence of urbanization on the relationship between cultural heritage sites and land use patterns. Landscape metrics were used to analyse land use pattern characteristics. Multi-scale correlation analysis assessed the association of cultural heritage sites and surrounding land uses. Regression analysis estimated the relationship of urbanization levels with the effects of cultural heritage sites on land use patterns. We found that cultural heritage sites significantly affect the pattern of land use and may possibly disturb and damage the ecological process. The results of this study may serve to inform more comprehensive land use policies that balance the needs of heritage preservation and ecological integrity.

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1 Introduction

Socioeconomic, political, technological and cultural values are regarded as the main driving forces for protecting cultural heritage sites (Howard and Pinder, 2003; Assi, 2012). Widespread understanding of their cultural significance, coupled with the threat of urbanizations, has led to the development of spatial heritage preservation policies (Chi, 2010). Although cultural heritage sites have been extensively studied, their effects on land use have not yet been adequately investigated (Bizzarro & Nijkamp, 1998; Melo, 2011; Logan, 2012). It is well understood that cultural heritage sites generate considerable spillover activities, such as roads and infrastructure development, tourist facilities, and employment (Chow, 2005). There is likely, then, a relationship between cultural heritage sites and their impact on surrounding land use patterns. Without an understanding of the relationship between cultural heritage sites and land use patterns, we are ill-equipped to assess the impact of current heritage preservation policies on ecosystem health. Our aim is to explore the relationship between cultural heritage sites and land use to instigate future research and support comprehensive development policies that integrate heritage preservation and ecological conservation.

For this study, we adopted the lens of landscape ecology, which focuses on the interactive relationship between land use patterns and ecological processes (Turner, 2005). Changes in land use are often driven by a broad spectrum of human activities (socioeconomic, political, technological and cultural) (Jiang et al., 2011; Schneeberger et al., 2007). Negative impacts of land use change disrupt the ecological landscape, as land use fragmentation damages the integrity of ecological processes and reduces ecosystem functioning (Buyantuyev et al., 2010). The effects of human activities on ecological systems can be understood by analyzing the spatial and temporal heterogeneity of land use patterns and evaluating their impacts on ecological processes (Riva-Murray et al., 2010; Kim & Pauleit, 2005). Land use pattern analysis and a variety of landscape metrics have been widely applied for this purpose (Yeh & Huang, 2009; Weng, 2007). We utilized this approach, taking care in our methodology that the metrics selected quantify the characteristics of land use patterns particular to the study area, as has been emphasized in the literature by Li & Wu (2004) and others.

We also assessed the relationship between cultural heritage sites and land use pattern change with regards to two components: scale and urbanization. The relationships between human activities and land use patterns are influenced by levels of urbanization and show different features in different regions of the city (Jenerette and Wu, 2001; Luck and Wu, 2002). Thus the effects of cultural heritage sites may vary under different urbanization levels. Additionally, given that the relationships between land use patterns and underlying processes are shown to be uniformly scale-dependent (Wu, 2004; Buyantuyev et al., 2010), and the effects of human activity vary at different scales, multi-scale analysis is therefore an important component of this land use analysis.

2 Materials and Methods

2.1 Study area and sites

Our research area is located in Hebei province on the northwest edge of the North China Plain, bordered by mountains to the west and the north and by a plain to the southeast (Figure 1). The area is part of the Haihe River Basin, which includes five large river systems: the Beiyun, Jiyun, Chaobai, Yongding, and Daqing. All of these river systems except the Beiyun flow through the study area. The area is characterized by a sub-humid, warm, temperate, continental monsoon climate (mean annual precipitation of 470–660 mm and mean annual temperature of 11–12 ℃). The area, which encompasses Beijing, presents the second highest degree of urbanization and the third fastest rate of urbanization in the country. Of the total area of 16,410.54 square kilometers, built-up districts cover 1,289.3 square kilometers. At the time of this study, this built-up area consisted of 16 districts or counties and had a resident population of 18 million people, with a population density of 1,341 people per square kilometer (making it fourth in the country in terms of population density after Macau, Hong Kong, and Shanghai). Beijing is one of the four largest municipalities in China, the second largest city in China, and the political, cultural, and transportation center of China. Beijing was founded over 3,000 years ago, and it has spent 849 years of its history as the country's capital. Many historical and cultural monuments remain in Beijing today.

The cultural heritage sites included this analysis were extracted from the Government of Beijing's lists of protected cultural heritage sites and span three categories, as shown in Table 2. In order to reduce the influence of specific site characteristics on results, we selected a large number of sites in three heritage categories (Table 1). We identified the spatial positions of these cultural heritage sites through GPS field investigations and a literature review (Figure 1).

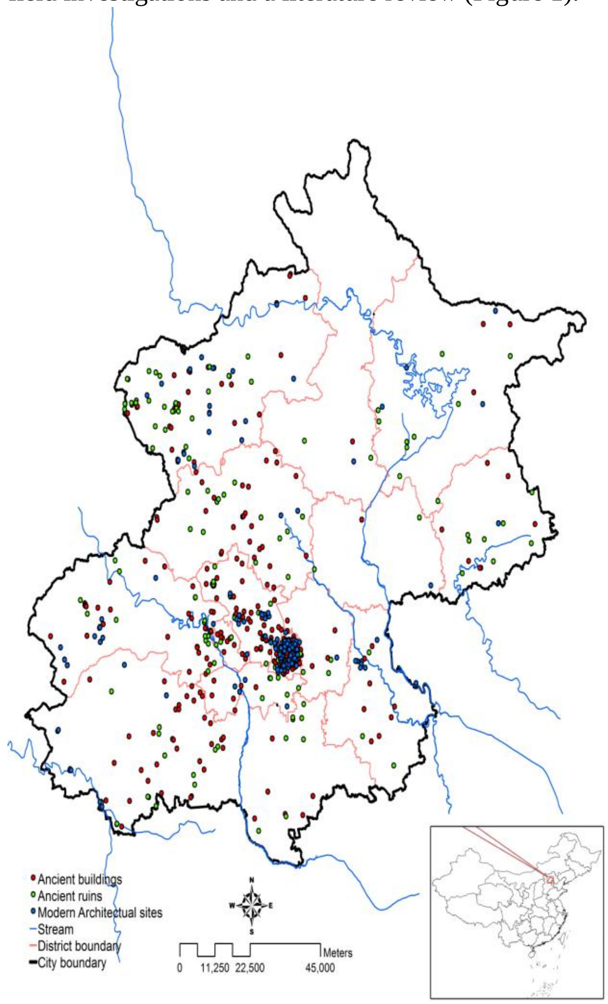

Figure 1. Location of Beijing

Table 1. Definitions of cultural heritage sites

Type	Description	Count
Ancient buildings	Remains of human-made architecture prior to 1840 that are intact, such as residential areas, villages and the capital of palaces, government offices, temples, workshops, etc.	456
Ancient ruins	Remains of human-made architecture prior to 1840 : structures that were once complete but have fallen into a state of partial or complete disrepair, due to lack of maintenance or deliberate acts of destruction.	133
Modern architectural sites	Remains of human-made architecture since 1840 that have historic, artistic or scientific value.	218

2.2 Land use and land cover map

A land use and land cover (LULC) map was produced from a geo-rectified and radiometrically corrected Landsat Enhanced Thematic Mapper (ETM+) image taken on September 6, 2006. We used geographic reference features (such as water, roads, dams, and city boundaries) from 1:50,000 scale topographic maps of Beijing to correct the image and classified land cover types using maximum likelihood classification. The final classification consisted of five classes (agricultural land, grassland, forest land, urban land, and water bodies) and yielded a reported overall accuracy of approximately 87.59% (Table 2). The user accuracy for individual classes varied from 80.22% to 90.99%.

Table 2. Accuracy assessment of the 2006 land-use/land-cover map

Class	Total Referenced	Total Classified	Number Correct	Producer Accuracy	User Accuracy	Kappa
Agricultural land	116	111	101	87.07%	90.99%	0.893
Grassland	100	91	73	73.00%	80.22%	0.7709
Forest land	339	351	312	92.04%	88.89%	0.7933
Urban and rural land	145	154	133	91.72%	86.36%	0.83
Water	33	26	23	69.70%	88.46%	0.8792
Total	733	733	642			
Overall Classification Accuracy = 87.59%						
Overall Kappa Statistics = 0.8212						

Table 3. Definitions of landscape metrics (McGarigal and Marks, 1995)

Name of landscape metric	**Description**
Area-Weighted Mean Shape Index (AWMPSI)	The average shape index (SHAPE) of patches, weighted by patch area
Mean Patch Shape Index (MPSI)	The average shape index (SHAPE) of patches in the landscape
Shannon's Diversity (SHDI)	Minus the sum, across all patch types, of the proportional abundance of each patch type multiplied by that proportion.
Shannon's Evenness (SHEI)	The observed Shannon's Diversity Index divided by the maximum Shannon's Diversity Index for that number of patch Types.
Contagion (CONTAG)	The observed contagion over the maximum possible contagion for the given number of patch types.
Edge density (ED)	The sum of the lengths of all edge segments in the landscape, divided by the total landscape area.
Area-Weighted Mean Fractal Dimension (AWMPFD)	The sum, across all patches, of 2 times the logarithm of patch perimeter divided by the logarithm of patch area, multiplied by the patch area divided by total landscape area.
Mean Patch Fractal Dimension (MPFD)	The sum of 2 times the logarithm of patch perimeter divided by the logarithm of patch area for each patch in the landscape, divided by the number of patches.
Largest Patch Index (LPI)	The percentage of the landscape comprised by the largest patch.
Landscape Shape Index (LSI)	The sum of the landscape boundary (regardless of whether it represents true edge) and all edge segments within the landscape boundary (including those bordering background), divided by the square root of the total landscape area.
Patch Size Standard Deviation (PSSD)	The root means squared error (deviation from the mean) in patch size.
Mean Patch Size (MPS)	The total landscape area, divided by the total number of patches.
Patch density (PD)	The number of patches in the landscape divided by total landscape area.

2.3 The selection of landscape metrics and landscape pattern analysis

Based on previous research on the ecological effects of human activities and land use pattern analysis, we selected 13 landscape-level landscape metrics to quantify land-use pattern characteristics with the help of the FRAGSTATS software (Luck and Wu, 2002; Wu, 2004; Buyantuyev et al., 2010) (Table 3). The compositional metrics used here include Shannon's diversity (SHDI), Shannon's evenness (SHEI), edge density (ED), the largest patch index (LPI), patch size standard deviation (PSSD), patch density (PD), and mean patch size (MPS). The configurational metrics used include the area-weighted mean shape index (AWMPSI), mean patch shape index (MPSI), contagion (CONTAG), area-weighted mean fractal dimension (AWMPFD), mean patch fractal dimension (MPFD), and landscape shape index (LSI). PD and ED quantify fragmentation in land use patterns (McGarigal and Marks, 1995; Aguilera et al., 2011; Zhang et al., 2004). LPI represents the proportion of the total area covered by the largest patch in a region (McGarigal and Marks, 1995; Armenteras et al., 2003). MPS and PSSD describe the distribution and central tendency of patch sizes (McGarigal and Marks, 1995; Andren, 1994; Herold et al., 2002). CONTAG is used to measure the degree of clumping of patches (Uuemaa et al., 2005). SHDI and SHEI indicate land use pattern fragmentation and equalization of class areas (Liu et al., 2012). LSI represents irregularity in the land use pattern (McGarigal and Marks, 1995; Herzog et al., 2001). MPSI, MPFD, AWMPSI and AWMPFD describe boundary complexities and fractal properties of individual patches of land (McGarigal and Marks, 1995; Herold et al., 2002; Ansley et al., 2001).

An empirically chosen 11×11-pixel (1650m) moving window was applied to calculate the landscape metrics in FRAGSTATS (Buyantuyev et al., 2010). The output from this procedure is a raster grid of each metric produced by passing the window over every pixel and writing the metric value for each individual window to the focal (center) pixel in the output grid (McGarigal and Marks, 1995).

2.4 Multi-scale correlation analysis

The distance decay effect states that the interaction between two objects declines as the distance between them increases (Smith, 1983; Paul, 1991; Fox et al., 2011). It has been widely developed as a quantitative technique to detect the land use effects of specific objects, such as road (Forman, 2000). In this study, to compare the effects of the different types of cultural heritage sites on land use patterns, cross-correlations between the landscape metrics and the distances to the cultural heritage sites were quantified and then used to compute Pearson's correlation coefficients in SPSS.

Based on the types of cultural heritage sites, 3 distance maps to the cultural heritage sites were calculated by using ArcGIS. The grid was bounded by the city boundary of Beijing. We then used an empirical 11×11-pixel (1650m) moving window to recalculate the distances to the cultural heritage sites by using focal statistics tool in ArcGIS. The output from this procedure is a raster grid of each distance map produced by passing the window over every pixel and writing the average value for each individual window to the focal (center) pixel in the output grid.

To examine the effects of scale on correlation between landscape metrics and distances to the cultural heritage sites, all maps were resampled from the original 1×1 pixel (150 m) grain size to an 8×8 pixel (1,200 m) on a side. The results are represented in Figure 2, showing only those results that meet at least a 0.05 significance level.

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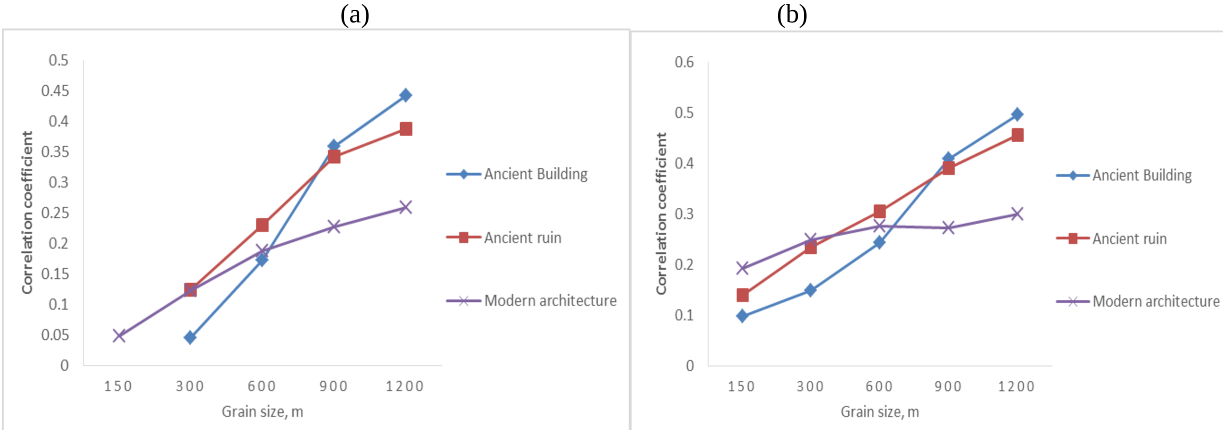

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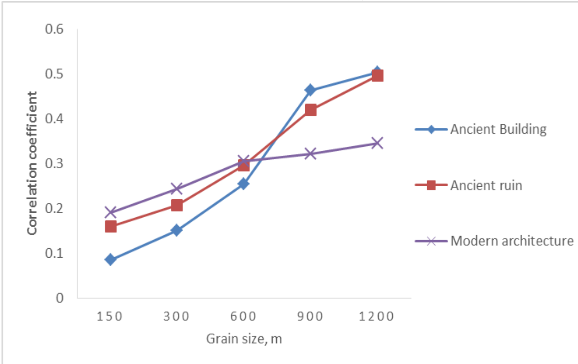
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Modern architecture

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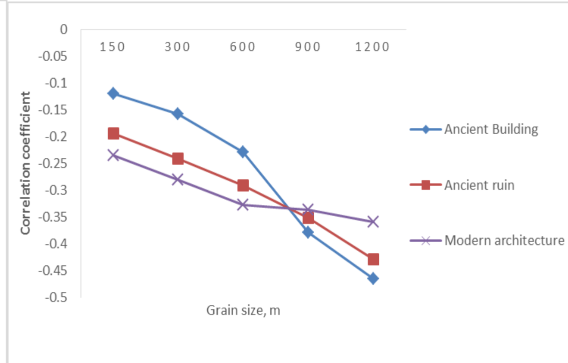
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Ancient ruin
Modern architecture

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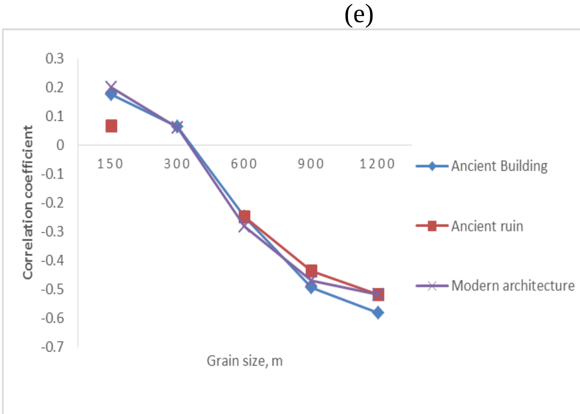
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Ancient ruin
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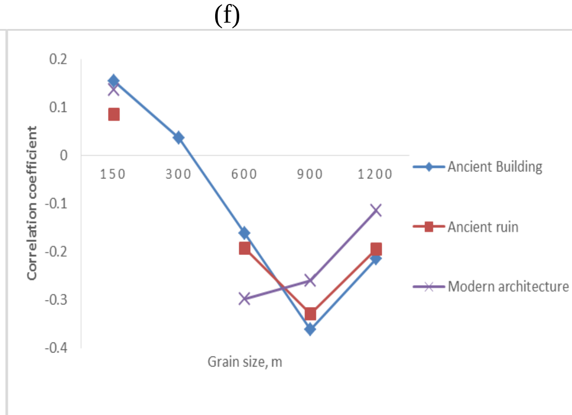
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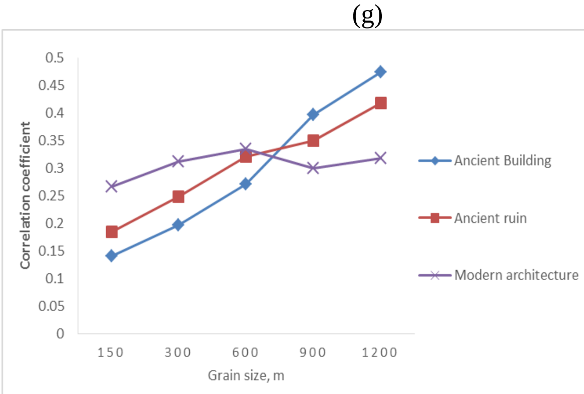
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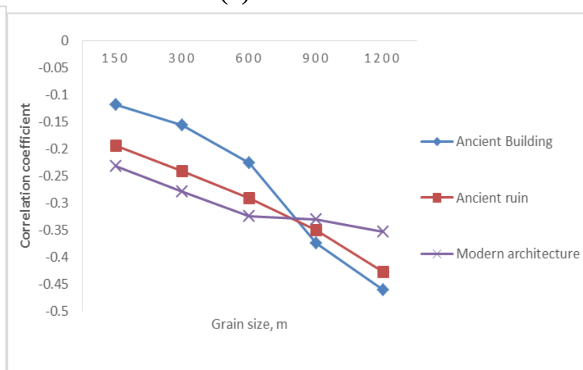
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Ancient ruin
Modern architecture

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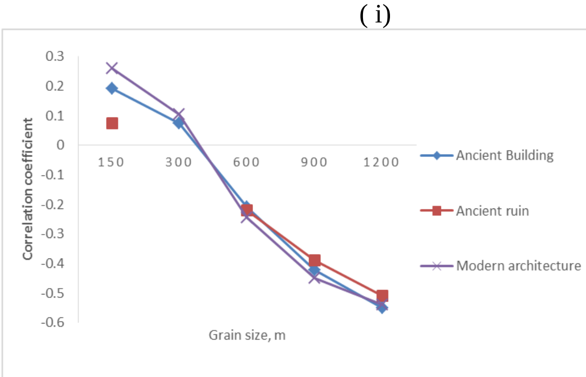
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Ancient ruin
Modern architecture

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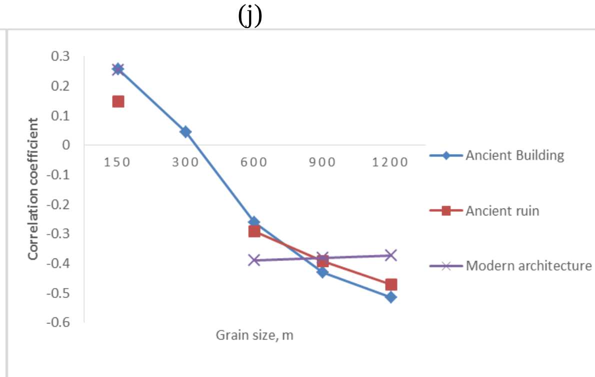
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Ancient Building
Ancient ruin
Modern architecture

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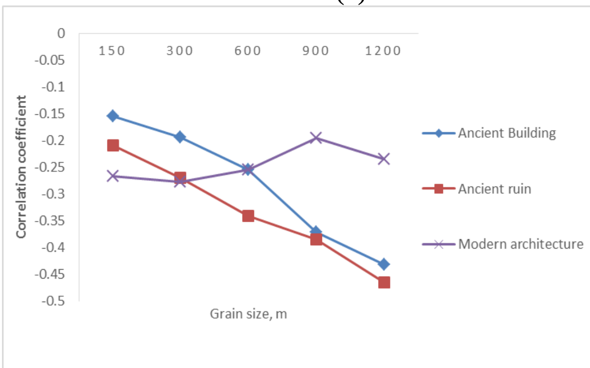

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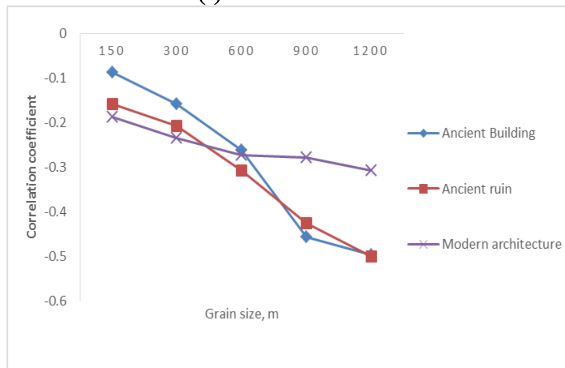

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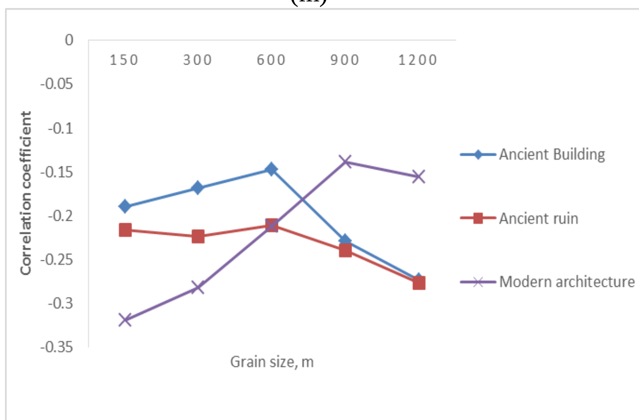

Figure 2. Effects of spatial resolutions on correlations between landscape metrics and distance to cultural heritage sites (a, Mean patch size; b, Patch Size Standard Deviation; c, Contagion; d, Edge density; e, Area-Weighted Mean Fractal Dimension; f, Mean Patch Fractal Dimension; g, Largest Patch Index; h, Landscape Shape Index; i, Area-Weighted Mean Shape Index; j, Mean Patch Shape Index; k, Shannon's Diversity; l, Shannon's Evenness; m, Patch density)

2.5 Regression analysis

Generally, the urban land ratio is used to measure urbanization levels (Huang et al., 2010; Allender et al., 2010). However, research shows that urbanization significantly influences the value of landscape metrics used to quantify land use pattern characteristics (Luck and Wu, 2002; Buyantuyev et al., 2010). Landscape metrics are therefore considered to more appropriate for measurement of urbanization levels (Hahs and McDonnell, 2006; Andersson et al., 2009). Based on previous research about the urbanization effects on land use patterns, PD, LPI, SHDI, PSSD, LSI and SHEI were selected to measure urbanization levels (Hahs and McDonnell, 2006; Andersson et al., 2009). To examine the effects of urbanization on the relationship between landscape metrics and distances to the cultural heritage sites, a linear regression model was applied. 16 subsets from 14 districts and two counties (the Chaoyang, Fengtai, Shijingshan, Haidian, Mentougou, Fangshan, Tongzhou, Shunyi, Changping, Daxing, Pinggu, and Huairou districts and Miyun and Yanqing counties) in Beijing were set as samples. Pearson's correlation coefficients, used to quantify correlations between the landscape metrics and the distances to the cultural heritage sites, served as dependent variables. Landscape metrics, used to measure urbanization levels, were input as independent variables in the regression analysis. Landscape metrics were calculated based on the average value of each metric and for each district or county. The regression analysis was computed at the 150 m × 150 m scale. The regression equation was selected based on AIC value and tested for multi-collinearity. The equation with minimum AIC value and a VIF value of less than 10 was considered to be most effective. The results are represented in Table 4, omitting results that are not significant or less than 0.05 significance.

Table 4. The estimated coefficient of the regression analysis between landscape metrics which used to measure urbanization level and correlation coefficients between landscape metrics and distance to cultural heritage sites ("—", Not included in the model)

	Constant	Shannon's Diversity	Largest patch index	Patch density	Patch Size Standard Deviation	R^2	**P**
Edge density - distance to modern architecture	0.998	1.059	—	—	—	0.455	<0.05
Largest patch index - distance to modern architecture	1.008	-0.986	—	—	—	0.299	<0.05
Landscape Shape Index - distance to modern architecture	-0.985	1.043	—	—	—	0.454	<0.05
Shannon's Diversity - distance to modern architecture	-0.932	—	—	0.247	—	0.395	<0.05
Shannon's Evenness - distance to modern architecture	-0.895	—	—	0.241	—	0.379	<0.05
Patch density - distance to modern architecture	0.517	—	—	—	-0.004	0.324	<0.05

3. Results

3. 1 Land use patterns characteristics near cultural heritage sites at different scales

Our Pearson's correlation analyses revealed that the distance to some types of cultural heritage sites were significantly correlated with many of the landscape metrics addressed in this study (Figure 3). Across scales, the relationships between these landscape metrics and cultural heritage sites showed consistent trends. We found that increased proximity to ancient buildings, ancient ruins, and modern architectural sites resulted in decreased values of PSSD, CONTAG, LPI, and MPS and increased values of ED, PD, LSI, SHDI, and SHEI. Additionally, we found that for some types of cultural heritage sites, the relationships with AWMPSI, AWMPFD, MPSI, and MPFD were affected by scale and exhibited different relationships. At small scales, the values of these metrics decreased with decreasing distance to ancient buildings, ancient ruins, and modern architectural sites. At larger scales, however, the values of these indices increased.

In general, correlations were low at the finest scale and increased with increasing grain size. Most of the correlations peaked at the 1200 m grain size, but some peaked at the 600 m grain size. This latter class of correlations included CONTAG vs. historic transport river, MPFD vs. moderarchitectural sites and LPI vs. modern architectural sites. In addition, the correlations of both PD and MPFD with the distances to ancient buildings and ancient ruins peaked at the 900 m grain size.

3.2 Land use patterns characteristics near cultural heritage sites under different urbanization levels

The urbanization levels proved to affect the relationship between distance to cultural heritage sites and landscape metrics (Table 4). The value of PSSD affected the correlations between modern architectural sites and PD; the correlations were positive at PSSD values below 103.5, and negative at higher PSSD values. The distance to modern architectural sites was negatively correlated with SHDI and SHEI at PD values below 3.8 and 3.7, respectively, and positively correlated with these metrics at higher values of PD.

The correlations between modern architectural sites and ED, and modern architectural sites and LSI were negative at SHDI values below 0.9, and positive at higher SHDI values. The correlation between architectural sites and LPI was positive at SHEI values below 1, respectively, and negative at higher values of SHEI.

4 Discussions

Cultural heritage sites are widely considered to require protection based on their economic, educational and social value (Howard and Pinder, 2003; Assi, 2012). Some spatial policies have been adopted to reduce the negative effects of urbanization on cultural heritage sites (Chi, 2010). Policies generally restrict conventional land use planning and building construction within a specified radius of cultural heritage sites (Swensen and Jerpasen, 2008; Beriatos, 2003). However, regulations have focused solely on heritage preservation, ignoring ecological impacts. Our correlation analysis between landscape metrics and distance to cultural heritage sites in the Beijing region help substantiate the relationship between cultural heritage sites and land use pattern change.

4.1 Land Use Pattern Analysis and Scale

In general, higher intensity of human activities are considered to result in more fragmented and more complex land use pattern and simpler individual patches (Luck and Wu, 2002). Our results from the land use pattern analysis confirmed that near ancient buildings, ancient ruins, and modern architectural sites, land use patterns became more fragmented, complex, and irregular. Land use pattern diversity also tended to increase near these sites. Additionally, the results indicated that at small scales, individual patches of land tended to be simpler and more regular closer to these sites, while at larger scales, the individual patches were more complex and irregular. Based on the decay effects, increased proximity to cultural heritage sites may represent a higher intensity of effects of cultural heritage sites on human activities which would result in higher intensity of cultural heritage sites based human activities (Geymen, 2009; Forman, 2000). Thus, it is conceivable that cultural heritage site activities may enhance fragmentation and complexity in land use patterns and yield more complex and irregular in individual patches. However, at the larger scale, individual patches of land tended to be more complex and irregular to these sites. One possible reason is the effects of scale on land use pattern. At the coarse scale, these maps have limitations in capturing the true shape of land uses on the ground (Lee et al., 2009).

4.2 Correlation Analysis and Scale

Our results revealed that the correlation coefficients for landscape metrics and the distances to cultural heritage sites varied across spatial scales. Some landscape metrics did not show any significant relationships with the distances to cultural heritage sites at all the scales. Several correlation coefficients peaked at some scales. This result is somewhat surprising because human activities have been proven to significantly affect land use pattern (Luck and Wu, 2002; Buyantuyev et al., 2010). One possible reason for the insignificant relationships between landscape metrics and the distances to cultural heritage sites may be related to the scales adopted in this study. From the landscape ecology perspective, the relationships between land use patterns and ecological process are highly scale dependent (Cumming et al., 2006; O' neill et al., 1996). Land use pattern characteristics interact with ecological processes (including human activities) and present different degrees of association under different scales (Lammert, 1999). Since we used several scales to detect the relationship between land use pattern and cultural heritage sites, we would expect that particular aspects of land use pattern characteristics would show different degrees of correlation under different scales. Additionally, this peak might indicate a specific scale at which each pair of variables interacts most strongly (Buyantuyev et al., 2010). If we do not examine the relationships between cultural heritage sites and land use patterns at the correct scale, we cannot properly evaluate the effects to inform land development policies. Based on our study, the scale of 600 m × 600 m should be used when investigating and discussing the land use pattern effects of modern architectural sites, while the scale of 900 m × 900 m should be adopted for ancient buildings and ancient ruins.

4.3 Impacts of urbanization

With the development of urbanization, the value of LPI and PSSD often tend to be smaller while the value of PD, SHDI and SHEI become bigger (Buyantuyev et al., 2010). Our results reveal that the relationships between some cultural heritage site activities and land use patterns were affected by urbanization levels. Although the relationship was not particularly strong, varying urbanization also played an important role in explaining changes in the relationships between cultural heritage sites and land use patterns. The other relationships showed unpredictable correlations with urbanization, which suggests that the relationships are insensitive to the urbanization, and in this case it is not possible to derive general relationships. We found that where the level of urbanization was generally low, land use patterns were more complex, fragmented and diverse near modern architectural sites and more complex near ancient buildings. Where the level of urbanization was generally high, this relationship was inverted.

The literature supports the notion that urbanization levels are a significant driver of human activities (Hersperger and Burgi, 2009; Zhu et al., 2007). However in this case, we see lower levels of land use impacts in areas of higher urbanization. One possible reason is that the intensity of activity surrounding heritage sites is lower than general activities in highly urbanized areas. As we know, lower intensities of human activities cause less impact on land use patterns (Luck and Wu, 2002).Beijing is a highly dense and active physical environment, whereas development policies restrict activity around heritage sites.

Threshold values have been found to be crucial for sustainable development and landscape planning (Bestelmeyer, 2006). In this study, some of the correlations between cultural heritage sites and land use patterns reversed direction above a threshold value for a given landscape metric, which was used to measure urbanization levels. The results reveal that when exceeding the specified urbanization level, some cultural heritage sites based human activities start to reduce ecological fragmentation, a negative impact of urbanization. Thus, such kinds of cultural heritage sites, such as modern architectural sites, should be protected when reaching a determined urbanization threshold. Based on previous research on biodiversity protection, ecological corridors and networks have been widely touted to protect ecological processes (Clarke and White, 2008). As human activities are an essential component of ecological processes, cultural corridors and networks may be useful for protecting the process of cultural heritage sites based human activities and should be established.

5 Conclusions

This study presented a correlation analysis to analyze the effects of cultural heritage sites on land use patterns and to examine the effects under multiple scales in the Beijing metropolitan area. Distances to cultural heritage sites were quantified to assess the association of cultural heritage sites and surrounding land uses. Landscape metrics were calculated for measuring the land use pattern characteristics. In addition, we conducted regression analysis to estimate the relationship of urbanization levels with the effects of cultural heritage sites on land use patterns. The results of our analysis can be used to better understand the role of cultural heritage sites in landscape and urban planning.

From the results of this study we reach the following conclusions: near ancient buildings, ancient ruins, and modern architectural sites, land use patterns were significantly affected under different scales. This study also helped identify specific scales at which it is most suitable to examine the cultural heritage sites effects on land use patterns. The results revealed that the scale of 600 m × 600 m should be used for modern architectural sites, while the scale of 900 m × 900 m should be adopted for ancient buildings and ancient ruins.

In this study, we assessed the effects of urbanization levels on the relationship between cultural heritage sites and land use patterns. The results revealed the relationships between some cultural heritage sites based human activities and land use patterns were negatively affected by urbanization levels, yet with increasing urbanization, the relationships were inverted. Additionally, this study helped identify threshold values. When exceeded, some types of cultural heritage sites, such as modern architectural sites, may reduce the negative ecological impacts of urbanization on land use patterns.

Overall, this study adds an important dimension to our understanding of the cultural heritage sites' significance by introducing landscape ecology approach and using landscape metrics and multi-scale analysis.

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