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RESEARCH ARTICLE

Buddhist monasteries facilitated landscape conservation on the Qinghai-Tibetan Plateau

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Abstract
Context The Sanjiangyuan region of the Qinghai-Tibetan Plateau—also known as the "Three Rivers' Headwaters"—is the origin of the Yellow, Yangtze, and Mekong Rivers and therefore the key water source for hundreds of millions of downstream residents. Protecting this region's ecosystems is a key priority for sustainable development in China and Asia. An important social dimension of Sanjiangyuan is the long-established and widespread presence of Tibetan Buddhism, particularly as manifested in the large number of monasteries throughout the region. However, the influence of cultural factors on environmental change remains largely understudied here.
Objective We focus on two types of spatial associations—point-point and point-area features—to quantitatively investigate the effects of Buddhist monasteries on land use/cover change (LUCC) in surrounding landscapes.
Methods We conduct a spatially-explicit analysis of Sanjiangyuan for two periods, 1990–2000 and 2010–2015, to identify and quantify the influence of the presence and spatial distributions of Buddhist monasteries on LUCC compared to village communities that lack monasteries.
Results We found that the presence of monasteries is highly correlated with the preservation of natural ecosystems, specifically of grasslands and forests. Within monastery buffer zones with radii between

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1 and 10 km, 7.13–9.30% more grassland area and 7.14–7.47% more forest area remained around monasteries compared to villages. This contrast decreased with increasing distance to the monastery/village. Overall, built-up areas were also much smaller around monasteries than around villages, while unused land was more commonly transformed to forests and grasslands around monasteries.

Conclusions These findings strongly support the idea that Buddhist culture, as manifested through its physical institutions and communities, are instrumental in achieving desired landscape conservation outcomes.

Keywords Buddhist monasteries · Landscape conservation · Land use cover change · Qinghai-Tibetan Plateau

Introduction

As one of the most environmentally fragile but also vital regions of the world, the Qinghai-Tibetan Plateau, also known as the 'Third Pole', has come under increasing pressures from both local and global changes. Worsening ecological problems include freeze–thaw erosion (Jiang et al. 2021), hydraulic erosion (Liu et al. 2021a, b), desertification (Liu et al. 2021a, b), grassland degradation (Wang et al. 2020; Shen et al. 2021), and salinization (Wang et al. 2021). The Qinghai-Tibetan Plateau, which boosts the world's highest mountains and a rich array of lakes and glaciers, is also called 'Asia's Water Tower' because it forms the upstream water source for nearly 2 billion people across Asia (Qiu 2008; Yao et al. 2012; Zhu et al. 2018). However, significant land use/cover change (LUCC) have occurred in this region in recent decades (Cui and Graf 2009; Qiu 2014; Han et al. 2016; Hopping et al. 2018).

LUCC is influenced by many factors that interact across scales, including cultural institutions (Kareiva et al. 1995; Wu 2010). On the Qinghai-Tibetan Plateau, such changes have attracted growing scientific attention, but studies have primarily focused on climate change, urbanization, and related government policies (Song et al. 2009; Han et al. 2016; Cheng et al. 2018). The influence of cultural factors have been widely neglected, despite the deeply-embedded influence of Tibetan Buddhism on many aspects of social life and human behavior in this region. Landscape protection is aimed at preventing the loss of ecological structure and functioning caused by the destruction of natural and cultural elements (Li et al. 2014; Shen et al. 2015). In many areas, culture plays a vital role in landscape conservation. As cultural factors subtly affect people's behavior, and indirectly affect land use. For example, in Tibetan Buddhist areas in Bhutan, religions prohibit local people from mining resources or construction in certain areas. The Buddhist beliefs of local people also preserve forests and biodiversity in sacred natural sites (Allison 2015). In India, one of the reasons for the restoration of groves in the sacred forests of the Western Ghats in India is "cultural taboos" (Shonil et al. 2014). However, how culture influence landscape change and protection has been difficult to quantify.

Having arrived over 1400 years ago, Buddhism is the dominant religion of the people living on the Qinghai-Tibetan Plateau, where it is deeply imbricated with social norms and practices. Buddhist monasteries are venues for assembly, interaction and instruction, and their grounds and surrounding areas are generally regarded as sacrosanct. Studies of Tibetan communities in China have found that Buddhist monasteries are often an important driver of biodiversity and landscape conservation (Harris et al. 1991; Shen et al. 2012a, b; Li et al. 2014; Shen et al. 2015). Central to Buddhism is a worldview that imbues natural formations, from mountains and rivers to the fauna and flora that inhabit them, with a sacredness that encourages environmental protection (Swearer 2001; James and Cooper 2007). A connection between Buddhist belief and ecological conservation has also been reported from field surveys of traditional communities in other parts of the world (Bhagwat and Rutte 2006; Kandari et al. 2014).

Most of the limited research that has been carried out on Buddhist monasteries focus on the architectural characteristics, building protection, and the other non-environmental dimensions. The spatial distribution of monasteries and the change in surrounding landscapes have been largely neglected. This study addresses this research gap by quantifying the spatial distribution of monasteries and its relationship with surrounding land use patterns. Earlier field investigations of on the Qinghai-Tibetan Plateau have identified Buddhist culture as a potentially important factor influencing LUCC (Yang et al. 2016; Yu et al. 2019), including through the propagation and enforcement of pro-environmental behaviors (Shen et al. 2012a, b). However, there have been few large-scale, spatially explicit studies that link religious institutions to landscape conservation. Here, we undertake such an analysis by combining field surveys with geospatially-referenced data to compare LUCC around monastery sites with LUCC around village communities without Buddhist monasteries. The primary hypothesis is that Buddhist monasteries exert a positive effect on the conservation of surrounding landscapes. Our study site is Sanjiangyuan, or the "Three Rivers Headwaters Region", of the Qinghai-Tibetan Plateau (Fig. 1). Its rich assemblage of forest, grassland and wetland ecosystems underscore its crucial ecological and cultural role in the greater plateau. The region has also been called "China's Water Tower" since it is the source of three major rivers—the Yangtze, Yellow, and Mekong—in whose downstream basins most of China's population live. In the case of the Mekong River, the sustainability of Sanjiangyuan is also crucially important for the development of neighboring Asian countries as well.

Methods

Study area

The study area (Fig. 1) includes the counties of the four Tibetan Autonomous Prefectures—Yushu, Guoluo, Hainan and Huangnan—along with the Tanggula Township of Geermu Prefecture in the Qinghai Province of China. Village location points were obtained from the Qinghai Geographic Information Center, while monastery location points were acquired from our 12 years of field surveys using GPS records of the region. A total of 306 monasteries and 877 villages were included to calculate their point-pattern distributions across the 17 counties. The study timeframe covers two periods, from 1990 to 2000 and from 2010 to 2015 (we had to exclude the time between 2000 and 2010 due to data quality issues for this time interval). The LUCC data were obtained from the Data Center for Resources and Environmental Sciences at the Chinese Academy of Sciences (RESDC) (http://www.resdc.cn), which has a spatial resolution of 1000 m (Fig. 2).

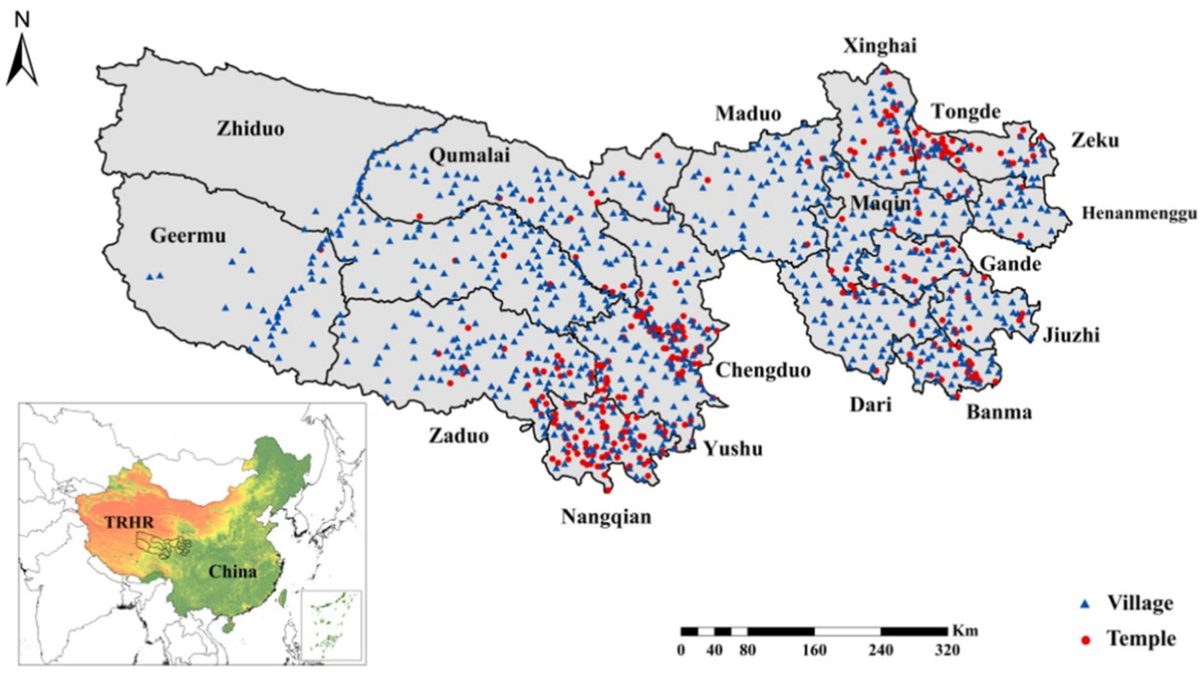


Fig. 1 The Sanjiangyuan, or "Three Rivers' Headwaters Region" (TRHR), is located across 17 counties in China's Qinghai province. Our study incorporated 306 monasteries and 877 villages from across the region

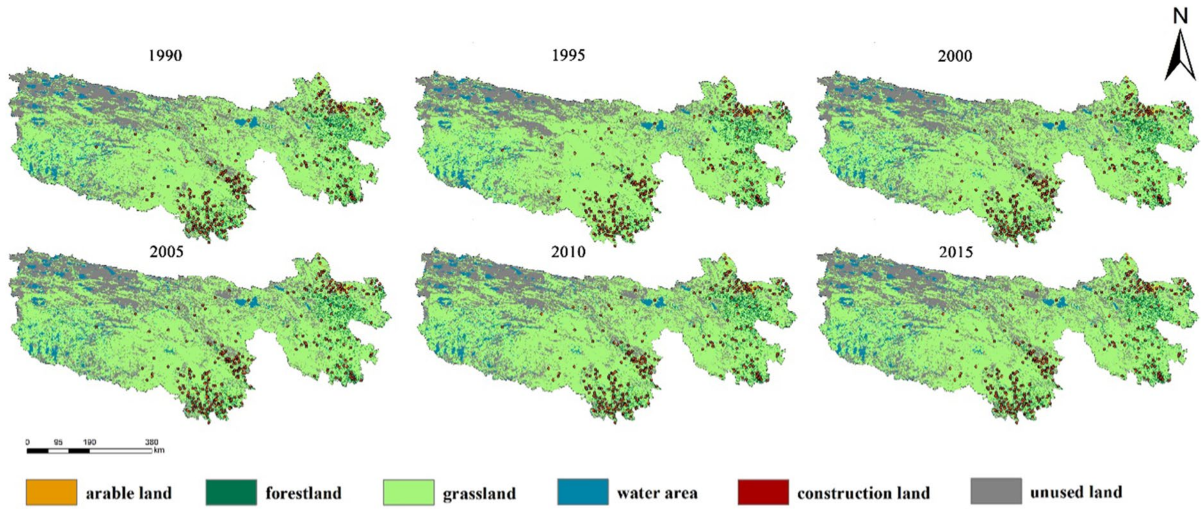


Fig. 2 LUCC map of Sanjiangyuan from 1990 to 2015

Data sources

Our research team, headed by the corresponding author of the paper, conducted numerous field survey of Tibetan Buddhist monasteries across Qinghai over a seven-year period from August 2, 2011 to August 20, 2018 as part of a long-term research initiative of Minzu University. Time in the field was concentrated in the months of July and August of each year, and in the month of the Tibetan New Year (February). Over the 7 years, the field surveys covered approximately 20,000 km and used GPS devices to record the spatial locations of identified monasteries, where resident abbots and monks were also interviewed. The survey data was also guided by, and later corroborated with, official registries of monasteries kept in the records of local governments.

Spatial datasets were collected as follows: First, we had two vector point datasets covering 306 monasteries and 877 villages. The names and location data were stored in shape files using Arc GIS 10.4.1. Data on village locations in the study area were obtained from the Qinghai Geographic Information Center. The village points in this study excluded large cities and counties, retaining only the villages of farmers and herders. And as mentioned above, data on monastery locations were obtained from field surveys conducted with each location ascertained through GPS. Second, we obtained six vector polygon datasets, with LUCC data covering the years 1990, 1995, 2000, 2010, and 2015, which were produced and curated by the Chinese Academy of Sciences Resource Environmental Data Center (RESDC) (http://www.resdc.cn). The data for 1990, 1995, 2000, 2010 had a resolution of 1 km by 1 km while the data for 2015 had a resolution of 30 m by 30 m, with an overall accuracy rate greater than 90% (Ning et al. 2018). Additionally, all the data were then resampled to an accuracy of 30 m. Land use/cover was classified in accordance with the classification standard system proposed by the Resource and Environment Information Center of the Chinese Academy of Sciences (Peng et al. 2011; Liu et al. 2014a, b). Level-one and level-two land cover types were selected for the study. More specifically, for our subsequent analyses, the level-one categories used were: arable land, construction land, forestland, grassland, water area, and unused land. ArcMap 10.4.1 was used to conduct the land cover reclassification.

Spatial analysis

We focused on two types of spatial associations—point-point and point-area features—to quantitatively investigate the effects of Buddhist monasteries on LUCC in surrounding areas. The first spatial association focuses on the respective point patterns of monasteries and villages within counties (villages in this case are defined as lacking monasteries in their direct vicinity and are therefore likely to exert a different effect on the surrounding landscape). The second spatial association is point-area-based and focuses on LUCC around monasteries and villages. Whether Buddhist monasteries can be said to influence surrounding environmental conditions is determined by whether there is a significant point-area-based spatial association between the village/monastery points and LUCC, and whether this spatial association is influenced by the point-point distribution pattern of said monasteries/villages. Since the landscape effects due to climate are the same for this monasteries and villages in the in study area, we did not incorporate related data.

We defined an indicator, $P_{(rq)}$, to quantify the spatial association between the monastery/village points and surrounding LUCC polygons within buffer radii of "rq" (r1 = 1 km, r2 = 2 km,…., r10 = 10 km) over three periods (1990–1995, 1995–2000, 2010–2015). Based on this function, the spatial relationship between monasteries and the surrounding LUCC polygons was calculated and a Monte Carlo model was used to statistically test the spatial relationship (this indicator only contained 16 counties since there was only one monastery point in one of the counties) (Fig. 3).

We conducted a point-pattern analysis using Ripley's K function, a widely-used method that determines the dispersion of points as a function of scale, and can more accurately analyze the degree of clustering over different distances (Dale 2000; Dale and Powell 2009; Arbia et al. 2017). Monasteries and villages were considered to be social centers with differing degrees of cultural influence on the surrounding landscape. Therefore, identifying these

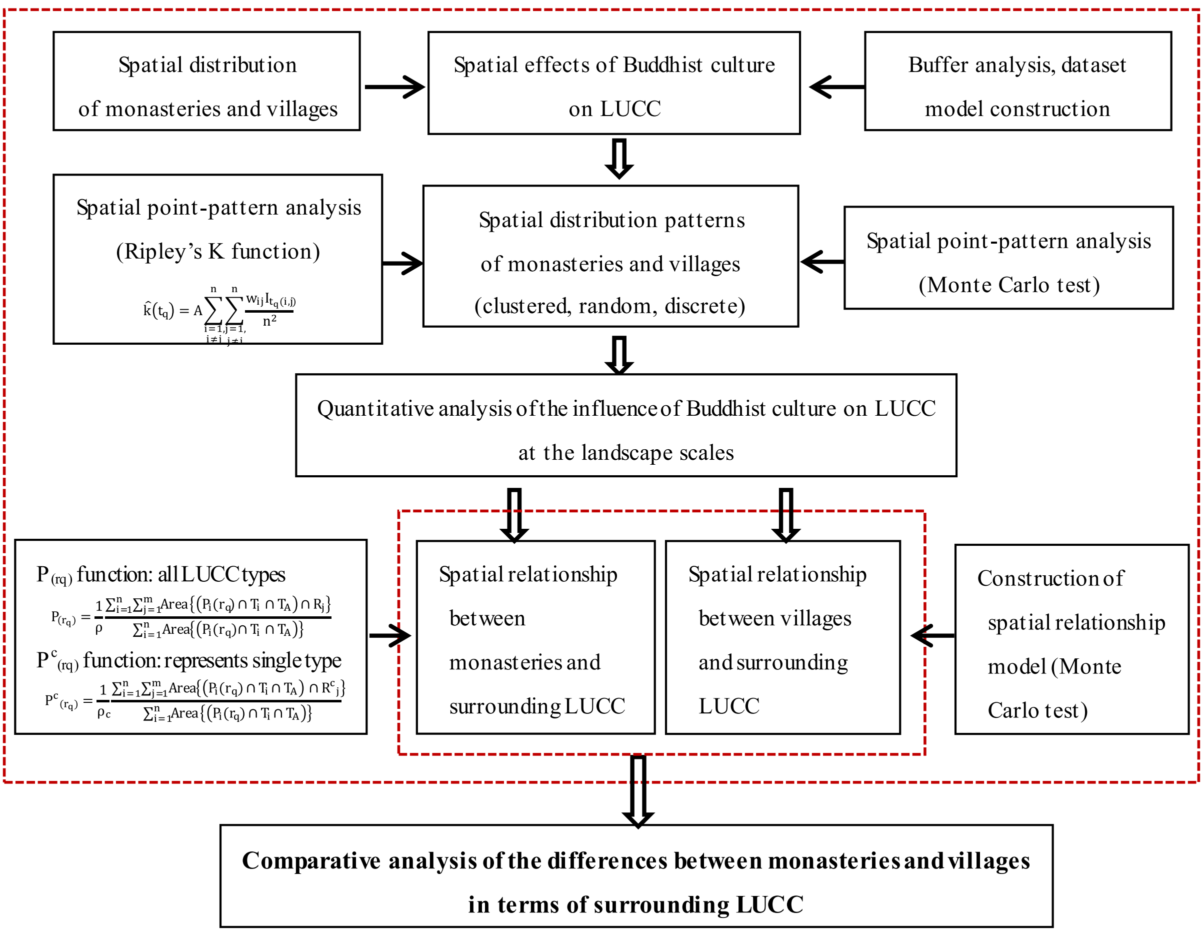


Fig. 3 The methodological framework used in this study

distribution patterns is critical to understanding whether and how monasteries and villages influence LUCC across spatiotemporal scales. There are three types of distribution patterns for control points (monasteries and villages): random distribution, aggregated distribution, and discrete distribution. The Ripley's K function value is calculated as follows:

$$\hat{k}(t_q) = A \sum_{i=1, i \neq j}^{n} \sum_{j=1, j \neq i}^{n} \frac{w_{ij} I_{t_q(i,j)}}{n^2} \quad (1)$$

where A is the area of the study region, d_{ij} is the distance between points i and j, n is the number of control points. I_t (i, j) is an indicator function if the distance of d_{ij} is less than t ($d_{ij} \leq t$), I_t is 1, if not, I_t is 0. "t_q" is the radius distance ($t_1 = d_{ij(er)}/10$; $t_2 = 2\ t_1$, $t_3 = 3\ t_1$, …, $t_{10} = 10t_1 = d_{ij(er)}$, and $d_{ij(er)}$ means 25% of the minimum range length of the minimum circumscribed rectangle of i and j. To account for the boundary effect, the numerator is weighted by w_{ij}.

Significance tests were obtained using Monte Carlo simulation, following Robinson (1998). First, a set of n random points in the subplot study region was generated according to the number of control points. Then, $\hat{k}(t)$ at t distance scales was calculated. Finally, the above two steps were iterated 999 times and the values were rank-ordered with the empirical values, with the confidence interval set to 99.9%. If the K(t) value for the observed data is larger than the upper confidence envelope (*HiConfEnv*) value, the clustering pattern of control points distribution is significant. Comparatively, if the value for the observed data is lower than the lower confidence envelope (*LowConfEnv*) value, the dispersed pattern of control points is significant. Otherwise, the control points present a random distribution pattern. Considering the set t_1, t_2, t_3, …, t_{10}, the values over these distances may be clustered or dispersed at certain distance scales but not at others.

LUCC reflects the influence of human activities on the surrounding landscape. To calculate the spatial association between points (monasteries and villages) and LUCC polygons, we estimated two indicators. The first calculated all LUCC types as a whole, which is indicative of the spatial association between monasteries/villages points and surrounding LUCC. The second concentrates on the primary LUCC types around the points. Finally, significance tests were obtained using Monte Carlo simulation. The first indicator seeks to determine whether the polygons are clustered or dispersed around monasteries/villages at various scales. We treat monasteries and villages as points located in the study area, and LUCC as polygons around the points. For a given point, all surrounding polygons within a given radius are considered as neighbors. If the radius is determined, the circular neighborhood (i.e., buffer zone) will be defined and remain constant across the whole study region to model the spatial relationships between polygons and points. The indicator of spatial association between points and polygons, $P_{(rq)}$, for all LUCC types at given distance r_q is:

$$P_{(r_q)} = \frac{1}{\rho} \frac{\sum_{i=1}^{n} \sum_{j=1}^{m} \text{Area}\{(P_i(r_q) \cap T_i \cap T_A) \cap R_j\}}{\sum_{i=1}^{n} \text{Area}\{(P_i(r_q) \cap T_i \cap T_A)\}} \quad (2\text{-}1)$$

$$r_q,\ r_1 = 1\text{km},\ r_2 = 2\text{km}, \ldots \ldots r_{10} = 10\text{km}$$

$$\rho = \sum_{j=1}^{m} \text{Area}(R_j)/\text{Area}(T_A) \quad (2\text{-}2)$$

where n is the total number of points located in the subplot study region (i.e., monasteries or villages), m is the number of polygons (i.e., polygons of LUCC during the study period), $P_{i\ (rq)}$ indicates the neighborhoods with radius r centered at control point i; as specified in (2-1), r_q refers to distance r (e.g., with $q = 1, 2, 3…, 10$; $r_1 = 1$ km, $r_2 = 2$ km…, $r_{10} = 10$ km). T_i indicates the Thiessen polygon of the control point i, R_j refers to the LUCC polygons, including all types of changes that took place in the study period; each polygon R_j has an attribute describing the type of LUCC (e.g., from forest to grassland, from construction land to arable land) during the study period; ρ is the density of all types of LUCC; and T_A is the subplot study region. In addition, given the radii r_1, r_2, r_3… and $P_{(r1)}$, $P_{(r2)}$, $P_{(r3)}$…, the sign ∩ refers to the intersection of several spatial objects, and the function Area{ } calculates the area of the space referred to inside the brackets. Consequently, the $P_{(rq)}$ indicator is defined as the ratio of the LUCC density of the neighborhoods around points to the LUCC density of the subplot study region.

Results

Spatial distribution patterns of monasteries and villages

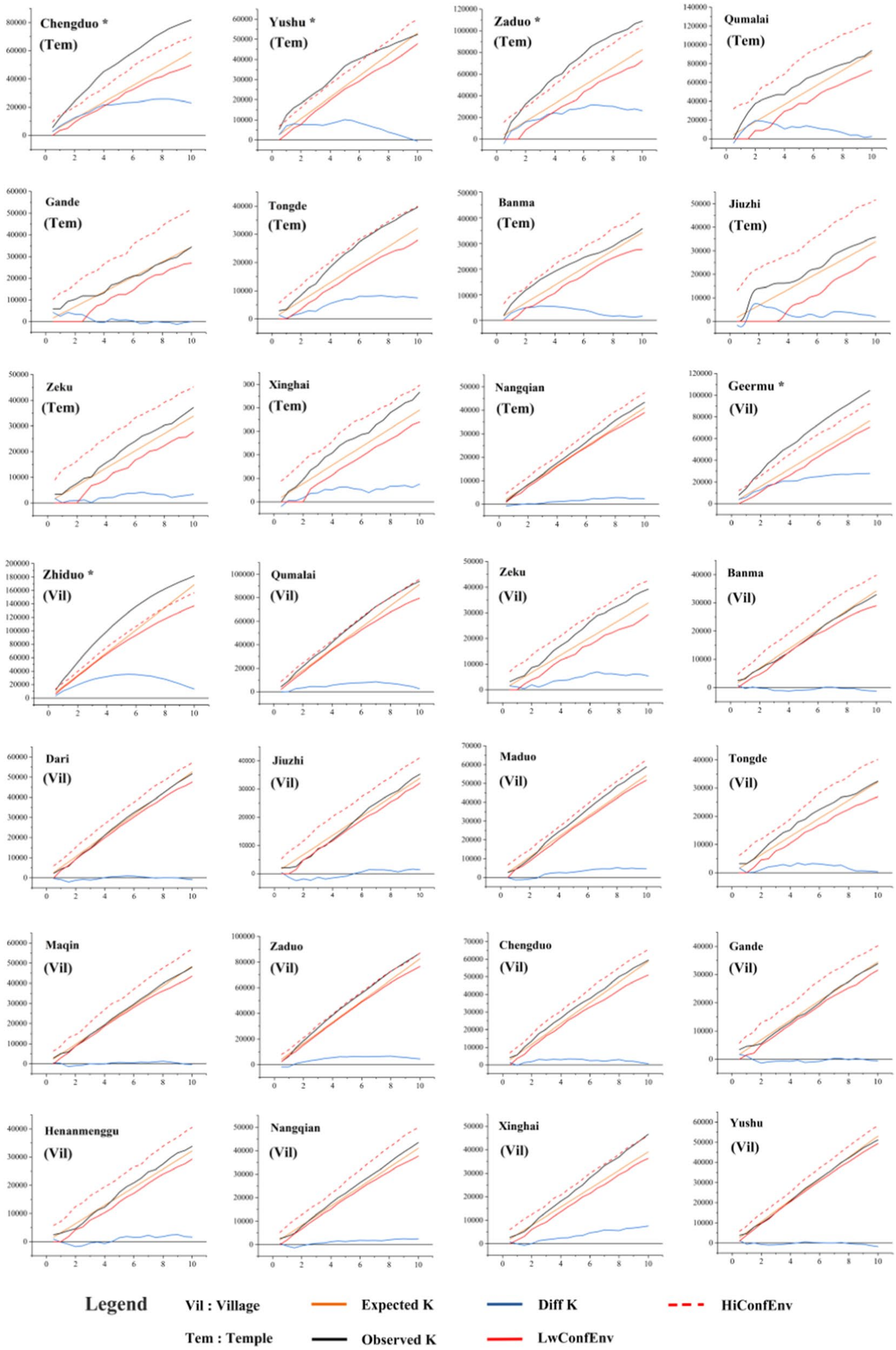
The spatial distribution of monasteries in Sanjiangyuan was uneven, with sites mainly located in the east and south, including the counties of Tongde, Banma, Chengduo, Yushu and Nangqian. Among them, monasteries in Nangqian accounted for the largest number, approximately 23% of the total. There were relatively few monasteries in the central and western areas, such as in the counties of Maduo and Zhiduo, and in Geermu city, which have extremely high altitudes and harsh environmental conditions even by the standards of the plateau. The spatial patterns of monasteries in 11 counties and villages in 17 counties in the study area met the operating criteria of Ripley's K function. There were two types of spatial patterns for monasteries, namely significant aggregation pattern and random pattern, with no significant discrete distribution pattern. Monasteries in Banma, Zeku, Xinghai, Tongde, Qumalai, Nangqian, Jiuzhi, and Gander counties were randomly distributed within the analytical radius of 10 km, while those in Chengduo and Zadoi counties were clustered within the same range. Those in Yushu showed a significant aggregation distribution within a radius of 8 km. Compared with the spatial patterns of monasteries, those of villages showed different distribution characteristics. With the exception of villages in Zhiduo and Golmud, which showed a significant aggregation distribution, villages in the other 15 counties all showed a random distribution pattern within the study area (Fig. 4).

The comparative influences of monastery and village distribution patterns on LUCC

As mentioned above, there are three types of spatial distribution for monasteries: clustered, random distribution, ad discrete distribution (Fig. 5). The LUCC polygons for a buffer zone with a radius of 1–10 km also tended to gather together when monasteries were clustered, as shown by the corresponding $P_{(rq)}$ values. This spatial change was especially obvious in Chengdu, Yushu and Zaduo counties (Fig. 6). When the buffer radius was less than or equal to 5 km, the monastery had a significant regulating effect on LUCC. However, this effect was not significant in counties with less than 10 monasteries. For example, more than 64% of $P_{(rq)}$ values in Dari, Mongol, Maduo, Maqin, and Zhiduo showed a random spatial relationship during the study period, and less than 36% of $P_{(rq)}$ values showed an aggregation relationship, especially during 2010–2015. 90% of the LUCC around monasteries occurred randomly, indicating that the influence of monasteries on surrounding ecological conditions weakened when their numbers were small.

In 1990–1995 and 1995–2000, discrete distribution appeared in buffer zones with radius ≥ 5 km, while for those with radius < 5 km, there was a random distribution. However, from 2010 to 2015, the P (rq) of Gander, Qumalai, and Tongde, within radii of 1–10 km, all showed significant aggregation. Additionally, the spatial relationship between monasteries and LUCC in Jiuzhi, Zeku, and Xinghai was not significant during 1990–2000, but showed a significant aggregation distribution during 2010–2015. Over time, there was a strong trend of monasteries clustering, especially between 2010 and 2015. In general, the randomly-distributed monastery pattern had no significant effect on LUCC compared with the clustered pattern. When clustered and distribution of monasteries had a significant influence on surrounding LUCC, the influence decreasing with increasing distance between monasteries. The clustering of monasteries can be said to intensify the clustering of LUCC polygons around them.

Compared to monasteries, the effect of village spatial patterns on surrounding LUCC exhibited a mixed association. Unlike with monasteries, there was no regularity in the relationship across spatiotemporal scales. Two counties (Geermu and Zhiduo) had clustered village distributions. Guermu's $P_{(rq)}$ value showed that LUCC within the 10-km buffer zone around villages were discretely distributed throughout the study period, and this significant discrete spatial relationship had a decreasing trend as the radius increased and the study period progressed. Jido's $P_{(rq)}$ value showed the opposite trend, as LUCC within the 10-km buffer zone were significantly clustered, with the clustering decreasing with the expansion of the radius and the passage of time. It is worth noting


Chengduo * (Tem)
Yushu * (Tem)
Zaduo * (Tem)
Qumalai (Tem)
Gande (Tem)
Tongde (Tem)
Banma (Tem)
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Zeku (Tem)
Xinghai (Tem)
Nangqian (Tem)
Geermu * (Vil)
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Qumalai (Vil)
Zeku (Vil)
Banma (Vil)
Dari (Vil)
Jiuzhi (Vil)
Maduo (Vil)
Tongde (Vil)
Maqin (Vil)
Zaduo (Vil)
Chengduo (Vil)
Gande (Vil)
Henanmenggu (Vil)
Nangqian (Vil)
Xinghai (Vil)
Yushu (Vil)
Legend
Vil : Village
Tem : Temple
Expected K
Observed K
Diff K
LwConfEnv
HiConfEnv

◂**Fig. 4** Different spatial distribution patterns of monasteries and villages

that the decreases in the degrees of clustering and dispersion indicate an increase in the spatial randomness of P $_{(rq)}$ in both counties. In general, the distribution pattern of the clustered villages did not have a strong and consistent effect on LUCC, in contrast to clustered monasteries (Fig. 6).

Villages in the remaining 15 counties were randomly distributed. LUCC in 6 of the counties (Qumalai, Zeku, Banma, Dazh, Mayu, and Hedo) showed random distribution, and their spatiotemporal trends can be classified into three broad types. The first was characterized by decreasing randomness and increasing clustering of surrounding LUCC polygons (Qumalai and Zeku). The second type showed the opposite trend: over the course of the study period, the randomness of LUCC around villages increased and the clustering decreased, especially for the period 2010–2015 (Banma, Dazh, Kuji, Mado, and Tongde). Finally, the third type showed clustering LUCC around villages in the 8 remaining counties (Ma'er, Meadow, Yu, Gande, Henan Mongolian, Baoqian, Xinghai, and Yushu) during the period 1990–2000, with the changes in their levels of distributional randomness and discreteness fluctuating with changing buffer radii. In general, LUCC around villages did not evince any regularity across spatiotemporal scales, having more complex spatial relations compared to monasteries.

As can be seen from Fig. 7, LUCC around monasteries during 1990–2015 were mainly clustered, followed by random distribution, and then by discrete distribution. And during 1990–2000, discrete distribution did not appear for radii smaller than 5 km. From 2010 to 2015, the spatial relationship of discrete distribution no longer existed, with clustered distribution being dominant. For villages, the main spatial pattern of surrounding LUCC during 1990–1995 was random distribution, followed by clustered and discrete distribution. As time went on, clustered distribution decreased while discrete distribution gradually increased. Buddhist monasteries exerted an obvious clustering effect on LUCC, and this effect increased from 2010 to 2015. In terms of villages, although discrete distribution increased, the random distribution of LUCC in the three periods was still the primary pattern. This indicates that villages in general did not have a significant impact on surrounding LUCC. Compared with villages, monasteries had a significant influence on the surrounding landscape.

The effects of monasteries and villages on changes to forests and grasslands

The two most common LUCC around monasteries were forest-to-grassland and grassland-to-forest. Monastery influence on these LUCC types was stronger when points exhibited clustered patterns as opposed to random patterns. Additionally, this monastery-influenced LUCC was more noticeable in the central part of Sanjiangyuan than in other areas, likely due to the significant clustering of monasteries there. However, in other parts of the region, as time progressed, there was also an increasing association between clustered monastery points and forest-to-grassland and grassland-to-forest transitions, suggesting an increase in Buddhist culture-mediated landscape change.

Additionally, the transformation of unused land around monasteries to grassland or forest was much greater than the respective transformations around villages, indicating a pro-environment influence of monasteries. This conclusion is further strengthened by the fact that increases in built-up land were also significantly lower around monasteries than around villages. The transformation of unused land to forest or grassland also increased with increasing distance. Finally, and perhaps most significantly, grasslands and forests surrounding monasteries stayed unconverted at consistently higher proportions compared to patches of these habitats surrounding villages given the same buffer size, with the differences between monasteries and villages increasing with increasing size of the buffer radius (Fig. 8).

Discussion

Landscapes are not only a link for interactions between diverse elements of the natural environment; they are also indispensable spaces for human settlement and activities, which both respond to and influence those environmental interactions (Liu et al. 2014a, b; Xie et al. 2020). As a consequence, LUCC are influenced by many factors that interact across spatiotemporal scales, from global processes

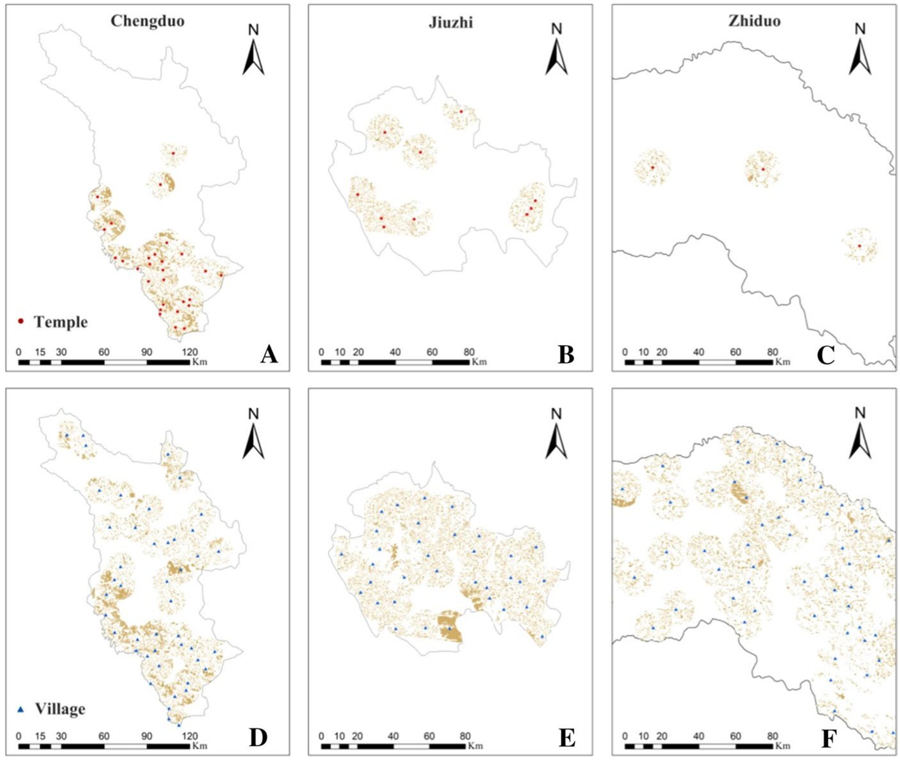

Fig. 5 Examples for point-point spatial distribution: **A**–**C** show LUCC within 10 km radius of monastery; **D**–**F** show LUCC within 10 km radius of village. The brown patches represent observed LUCC within 10 km radius

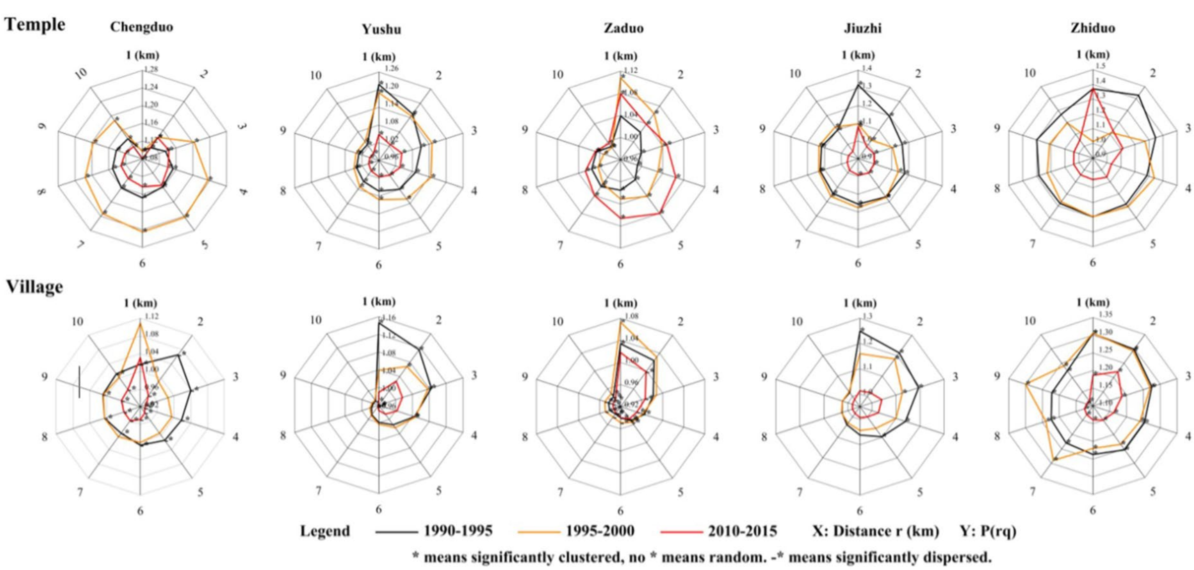

Fig. 6 Point-area relationships for five Sanjiangyuan counties

of climate change to the effects of cultural institutions. Therefore, it is important to study how such geographically-widespread and socially-imbedded institutions as Buddhist monasteries influence surrounding ecological change on the Qinghai-Tibetan Plateau. Understanding these dynamics is crucial to

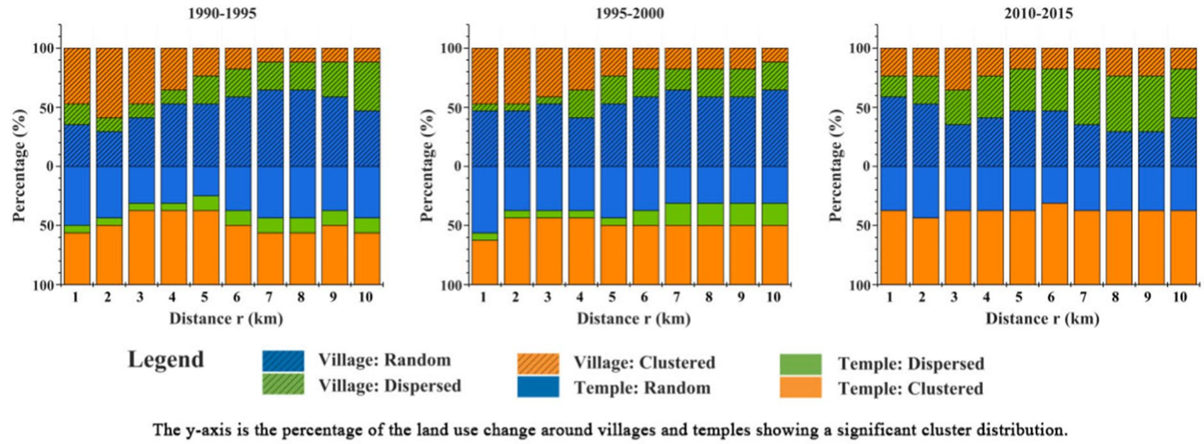

Fig. 7 Differing distribution patterns of monasteries compared to villages (without monasteries)

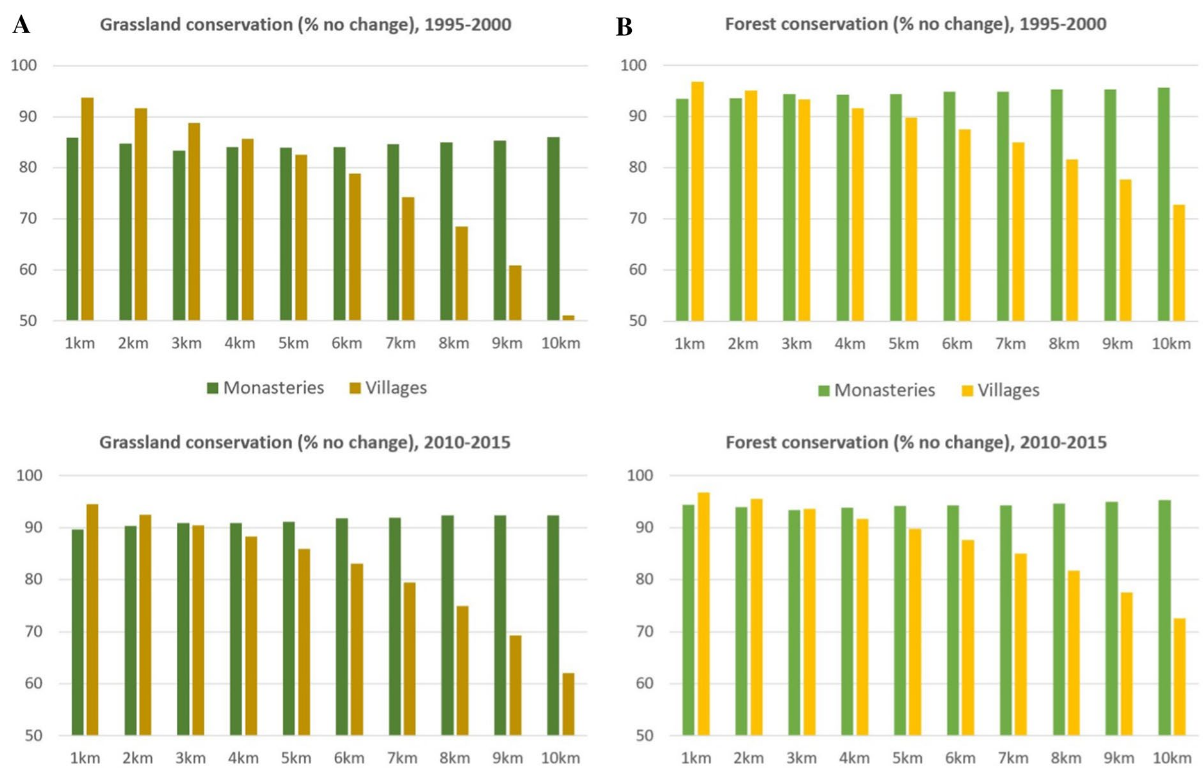

Fig. 8 Influence of monasteries and villages on existing grassland (**A**) and forest (**B**) habitat patches in their vicinity. The farther the distance from a monastery/village, the greater the contrast in this conservation effect between the two types of communities

ensuring the sustainable development of this culturally and ecologically vital region in an era of environmental change (Wu 2013).

In this study, we found that Buddhist monasteries had a strong influence on surrounding LUCC. In particular, the results showed that the degree of LUCC was higher than expected and that more LUCC were clustered around monasteries at a given distance than would be expected by chance. This "clustering effect" was more pronounced within a radius of 5 km, meaning that the farther away from a Buddhist monastery, the lower the intensity of its effect on LUCC. Additionally, the greater the clustering of monasteries, the greater the influence on surrounding LUCC. Moreover, when the monasteries showed a more randomly-distributed pattern, surrounding LUCC did not present a corresponding random pattern. This showed that since there is a strong effect on LUCC regardless of distributional patterns, it was the Buddhist monasteries themselves, with their distinct cultural characteristics, that was an important driver of landscape change.

In contrast, we did not find a similarly straightforward association between the distributional patterns of villages and surrounding LUCC. Sanjiangyuan has a diverse composition of communities, and there were likely differences in terms of land use across villages, further reinforced by different policies in different jurisdictions, such as grazing prohibitions, which were limited to some parts of the study areas, as well as different levels of compensation for conservation and restoration efforts (Wang et al. 2015, 2016). The point-area dynamics of villages therefore provide an important contrast to the strong and consistent effects on LUCC found for Buddhist monasteries.

Our analyses found that natural ecosystems, namely grasslands and forests, were conserved at significantly higher levels in areas surrounding monasteries compared to village communities without monasteries. Additionally, there was considerably less built-up land around monasteries than around villages, and unused land was more likely to be transformed into grasslands or forests around the former than around the latter. These findings accord with fields studies and other investigations that have found Buddhist monasteries in China and elsewhere in Asia to exert a pro-conservation effect on surrounding landscapes (Harris et al. 1991; Shen et al. 2012a, b; Li et al. 2014; Shonil et al. 2014; Shen et al. 2015; Allison 2015).

These findings have critical implications for the sustainability of Sanjiangyuan. The region's forests and grasslands provide many important ecosystem services, including carbon sequestration, water retention and supply, and the provisioning of timber and foodstuffs, the viabilities of which have come under growing threat from landscape degradation and climate change (Wen et al. 2013; Jiang et al. 2016). Additionally, the region provides habitats for highly endangered species such as the snow leopard (*Panthera uncia*) and Tibetan antelope (*Pantholops hodgsonii*). Sanjiangyuan is also a culturally vital region, where Buddhism has thrived for over a millennium and continues to permeate many aspects of social life (Ji 2012; Yu 2013). Buddhist monasteries are the most concrete manifestations of this cultural dispensation.

Our findings strongly support the hypothesis that Buddhism has a significant effect on the interactions of local communities with their surrounding landscapes. This also consolidates earlier studies that outline the role Buddhist monasteries play in encouraging communal participation in conservation activities from organizing conservation patrols to enforcing a disciplinary regime that included punishments for environmentally deleterious behaviors (Shen et al. 2012a, b). Therefore, Buddhist monasteries are a crucial link between Sanjiangyuan's social and ecological systems, and the sustainability of local landscapes can be further advanced through the protection and promotion of Buddhist monasteries and their cultural role in this region.

In other parts of the Qinghai-Tibetan Plateau, urban expansion has already encroached upon a significant number of monasteries and their associated communities, leading to cultural as well as ecological detriment. This makes the preservation of remaining sites and their surrounding landscapes even more urgent (Zhang et al. 2018). A major and immediate policy implication concerns the newly-established Sanjianyuan National Park, which covers our entire study area. At 123,100 km^2, Sanjiangyuan National Park will be approximately 13.7-times the size of Yellowstone National Park in the United States. Unlike national parks in the US, however, there will still be a long-term and relatively large human population living within its boundaries. Many inhabitants have emigrated or been relocated to the nearby urban centers in recent years, but tens of thousands of pastoralists and villagers are likely to remain for the foreseeable future (Wang et al. 2010; Shen and Tan 2012). This is a major opportunity as well as challenge for sustainability, given the long history of harmonious interaction between local residents and their biodiverse environment, in addition to the broader mandate of protecting Sanjiangyuan's highly valuable natural resources and landscapes. Going forward, this mandate should incorporate the protection of its Buddhist monasteries and the promotion of the cultural traditions that they embody.

Conclusions

This study used a spatially-explicit analysis of the Qinghai-Tibetan Plateau for two time periods—1990–2000 and 2010–2015—to quantify the influence of Buddhist monasteries on LUCC (or lack therefore, implying landscape conservation) compared to village communities that lacked monasteries. We found a "clustering effect" in which the spatial aggregation of monasteries was highly correlated with the preservation of natural ecosystems, specifically of grasslands and forests. Within monastery buffer zones of radii between 1 and 10 km, 7.13–9.30% more grassland area and 7.14–7.47% more forest area remained. This contrast decreased with increasing distance from the monastery/village. Overall built-up areas were also much smaller around monasteries than around villages, while unused land was more commonly transformed to forests and grasslands around monasteries. These findings strongly support the idea that Buddhist culture—both through its physical institutions and related communal influence—are instrumental in achieving desired ecosystem conservation outcomes.

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Declarations

Conflict of interest The authors declare no conflict of interest.

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