

# Integration of InVEST-habitat quality model with landscape pattern indexes to assess mountain plant biodiversity change:

## A case study of Bailongjiang watershed in Gansu Province

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**Abstract:** Mountains in western China, hosted rich biodiversity and millions of people and inhabitant with vital ecosystem services, had experienced the most serious biodiversity loss with fragile ecological problems. Even though increasing attentions had been paid to this issue, we still lacked efficient methods to assess the change of plant biodiversity at medium/large scale due to the poor data and co-existing multiple habitat types. This study proposed an integrated method combining InVEST-habitat quality model, NPP and landscape pattern indexes to analyze the spatial heterogeneity of plant biodiversity and its spatiotemporal change on raster cell scale. The results indicated that plant biodiversity service was high in Bailongjiang watershed with obvious spatial pattern variations. The land area containing higher plant biodiversity were 3161 km<sup>2</sup>, which mainly distributed in the National Nature Reserve and forestry area. While the areas with lower plant biodiversity accounted for 37.67% and mainly distributed in the valleys between Zhouqu-Wudu-Wenxian County, the valley of Minjiang in Tanchang County and alpine mountain snow-covered regions. During 1990–2010, plant biodiversity level tended to increase and the higher plant biodiversity area increased from 14.13% to 17.15% due to ecological restoration and afforestation, while plant biodiversity decreased in the area with intensive human activities, such as cultivated land, urban and rural land. The results showed that combining InVEST-habitat quality model, NPP and landscape pattern indexes can effective reveal mountain plant biodiversity change. The study was useful for plant biodiversity conservation policy-making and human activity management for the disaster-impacted mountainous areas in China.

**Keywords:** spatial change; habitat quality; landscape pattern; plant biodiversity conservation; InVEST model; Bailongjiang watershed in Gansu Province

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## 1 Introduction

Biodiversity, generally referred to the variety and variability of life on Earth, was the material foundation and the environment guarantee of human survival and sustainable development (Butchart *et al.*, 2010; Isbell *et al.*, 2013). Biodiversity typically measured variation at the genetic, the species, the ecosystem (UNEP, 2010) and the landscape level (Batáry *et al.*, 2012; Liddicoat *et al.*, 2018). Landscape biodiversity was a description of the number and dominance of different patch types contained within a spatially heterogeneous area (Batáry *et al.*, 2012; Liddicoat *et al.*, 2018), and was the premise foundation for identifying key biodiversity (priority) protection areas at geographical scale. Although biodiversity protection continuing to increase in recent decades, biodiversity loss was still a huge challenge throughout the world due to the global environmental change, invasive species and human activity disturbance (Chaplin-Kramer *et al.*, 2015; Zhao *et al.*, 2015). Meanwhile, how to efficiently allocate the limited money and human resources for biodiversity conservation to maximize its benefits was one of the major challenges of biodiversity science-policy and management. Therefore, spatial assessment and mapping of regional biodiversity at geographical perspective were urgently needed, which had been taken up worldwide by politicians and the public.

Change of plant biodiversity was one of the impacts of landscape fragmentation and habitat change, which associated with land use change. The change and fragmentation of habitats were regarded as currently the most pervasive, ubiquitous anthropogenic drivers (in addition to the introduction of invasive species, and the direct use of biodiversity) (MA, 2005; Wilson *et al.*, 2016). Landscape patterns provided the foundation for ecological processes (Turner and Gardner, 2015), so its change (e.g. landscape heterogeneity or structure change) affected habitat quality (Guiomar *et al.*, 2015). Thus, landscape change was related to ecological diversity (Walz and Syrbe, 2013; Schindler *et al.*, 2013; García-Llamas *et al.*, 2018), and currently there was increasing consideration of landscape as the most suitable scale for biodiversity assessment and management actions (Rossi and van Halder, 2010; García-Llamas *et al.*, 2018). That was, biodiversity might be expressed at landscape scale (Turner *et al.*, 2003; Turner, 2014), and could be generally determined in two ways by the landscapes scale. One was the variety of biophysical conditions of the landscapes structure (Walz and Syrbe, 2013), such as biomass, floristic compositions, vitality and productivity, taxonomic and phylogenetic, plant species patterns and heterogeneity (alpha, beta, gamma diversity) (Turner *et al.*, 2003; Turner, 2014; Lausch *et al.*, 2016). And vegetation Net Primary Productivity (NPP) could reflect the natural vegetation biomass and production capacity, and also was a key factor for gauging terrestrial ecosystem health, quality, elastic and biodiversity (Zhang *et al.*, 2014; Liu *et al.*, 2015; Wang *et al.*, 2016), especially in the farming-pastoral zone or mid-latitude and semi-arid region. The higher NPP in these regions mentioned above, the more complex terrestrial ecosystems and the richer of biodiversity at the landscape level (Xie *et al.*, 2017; Liddicoat *et al.*, 2018). The other one was landscape fragmentation, connectivity and land use pattern change (de Chazal and Rounsevell, 2009), which could be reflected by landscape pattern indexes (Haines-Young, 2009; Lausch *et al.*, 2016). Landscape pattern indexes were a set of quantitative indicators that reflected the structural composition and spatial distribution of the landscape (Plexida *et al.*, 2014), and

some of them were applied for biodiversity assessment or a proxy of species richness (Rossi and van Halder, 2010; Ng *et al.*, 2013; Santini *et al.*, 2017), such as landscape connectivity, Sørensen similarity index, Shannon index and other metrics of landscape structure (e.g. shape, fragmentation, separation index, etc.). For example, Santini *et al.* (2017) found that separate metrics of species abundance and landscape structure should be used to reflect biodiversity changes like the composite metrics (e.g. Shannon index). Schindler *et al.* (2013) found that landscape metrics were good indicators for overall species richness, woody plants, orthopterans and reptiles. Rossi and van Halder (2010) found that certain landscape attributes could potentially serve as indicators for butterfly species richness at the landscape scale. In addition, landscape pattern indexes were easier to get by the newly developed remote sensing (RS) and Geographic Information Systems (GIS).

Recently, with the development of RS, GIS, satellite tracking and ecological model, quantification and visualization of the regional biodiversity evaluation at spatial scale and time scale was widely used (Scholes *et al.*, 2012; Lausch *et al.*, 2016; Remme *et al.*, 2016). In addition, identifying and understanding the spatial variation of biodiversity at regional scale was the highlight of biodiversity conservation and research, and a lot of associated work were carried out (Santini *et al.*, 2017; Vihervaara *et al.*, 2017; Peng *et al.*, 2015; Mitchell *et al.*, 2015; Wu *et al.*, 2016). For example, Vihervaara *et al.* (2017) discussed national biodiversity monitoring of Finland with regarding essential biodiversity variables and remote sensing. Lausch *et al.* (2016) provided a comprehensive review of the role of earth observation to detect, describe, predict and assess biodiversity. Li *et al.* (2012) took counties as the evaluation unit to assess the biodiversity and its spatial distribution in Chengdu-Chongqing Economic Zone of China. Thus, potential biodiversity variables to be retrieved from satellite remote sensing include pertinent indicators of ecosystem function and structure. And then, increasing the understanding of spatial and temporal processes and patterns at multiple scales was considered a key area of future research in mountain biodiversity (Payne *et al.*, 2017) and landscape ecology (Wang *et al.*, 2017), although currently the spatial and temporal pattern of biodiversity research based on the grid unit at the regional scale was relatively rare in China (Nelson *et al.*, 2009; Murguía *et al.*, 2016).

Meanwhile, traditional biodiversity research and conservation focused on the species, community and ecosystem level based on the extensive and intensive monitoring schemes, ecological sample and ground field survey, etc. Moreover, biodiversity monitoring works were mostly well-carried out in the developed countries with adequate resources devoted, however, in developing countries (e.g. China, Nepal, etc.), collecting and organizing data for biodiversity was a huge challenge for the national and local governments because of budget and human resource limitations (Kohsaka *et al.*, 2013). In China, due to the lack of a comprehensive biodiversity data and the absence of spatial data, the spatial variation of biodiversity at national (or regional) scale was difficult to be implemented. Moreover, for the remote and mountainous areas, the basic data of biodiversity was not enough for its spatio-temporal change study, even in some of the local national nature reserves. So, it was really needed to set up new methods for biodiversity assessment from the geographical and landscape perspective to fill these gaps.

It was also urgent needed that biodiversity research and conservation policy in the multiple scales (e.g. global, national, regional and local, etc.) for its application and decision

making (Boykin *et al.*, 2013), especially in mountainous areas which are lack of monitoring data and confronting huge conflict between biodiversity protection and human activities. To overcome the shortage of biodiversity monitoring data, methods from multi-disciplines and technological ways had been developed recently, such as, representative sampling and estimate methods including design-based or model-based (Butchart *et al.*, 2010; Buckland and Johnson, 2017), high-resolution satellite images (Convertino *et al.*, 2011), utility of land use data and landscape ecological methods (Santos *et al.*, 2016; Plexida *et al.*, 2014; Xie *et al.*, 2017). And then, many empirical studies had been conducted for plant biodiversity evaluation and spatial pattern based on the integration of ecological models (such as Integrated Valuation of Ecosystem Services and Trade-offs, shorted as InVEST model), 3S technology and (or) landscape pattern metrics. For instance, Polasky *et al.* (2011) used InVEST model to quantify the changes in ecosystem services and biodiversity in Minnesota, USA. Xu *et al.* (2013) identified and calculated the biodiversity hotspots by InVEST biodiversity model in the Wenchuan earthquake-hit area. Liang and Liu (2017) analyzed the effects of different land-use patterns on biodiversity change based on InVEST biodiversity model and simulation method in Zhangye, China. In summary, integration of InVEST model, satellite image and landscape ecological methods to assess the regional biodiversity was feasible (Lausch *et al.*, 2016; Remme *et al.*, 2016; Xie *et al.*, 2017).

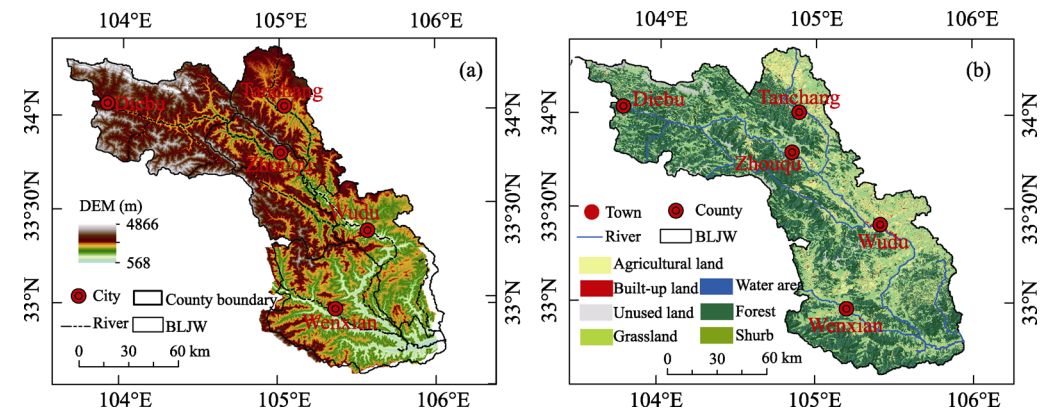
Chinese mountainous areas, with very rich biodiversity, are home to millions of people with vital ecosystem service (Payne *et al.*, 2017). Located in the farming-grazing transitional region, Bailongjiang Watershed (BLJW) of Gansu Province is well-known for its rich biodiversity in western China. There are some extant ancient plants and a great variety of wild plants and animals surviving in the BLJW, with more than 2160 species of 197 series of spermatophyte. However, the wild plants and biodiversity are facing huge threats from habitat loss and landscape fragmentation because of population growth, human disturbance (e.g. mining, tourism, etc.) and frequency of geological disasters (e.g. landslides, debris flow, etc.). Therefore, BLJW can be a good case for exploring and quantifying plant biodiversity change in the fragile hilly area and serve as a good pilot for lessons and provide methodological and practical guidance for plant biodiversity pattern and conservation in western China.

In this study, we tried to establish a comprehensive index system of plant biodiversity spatial patterns, analyzed and assessed spatial differentiation at the landscape level, to address two questions: (1) what was the spatial pattern of plant biodiversity of BLJW, and (2) were InVEST-habitat quality model with landscape pattern indexes useful to assess mountain plant biodiversity change? The aims were to construct a comprehensive index as a proxy with integration of InVEST model, NPP and landscape pattern indexes for plant biodiversity change at the landscape geographical perspective, and BLJW was selected as a case to illustrate the usefulness of this integrated index in the mountainous areas of China. Hoping the results could be used to support spatial planning and protection of biodiversity in watershed landscape, especially for the fragile mountainous area.

## 2 Study area

Bailongjiang Watershed (BLJW) in southern Gansu located between 103°00'–105°30'E and 32°36'–34°24'N (Figure 1a) and in the transitional ecotone among the Tibetan Plateau, Loess Plateau and Qinling-Daba Mountains, characterized by geological structural fissure and

fragmentation with steep terrain and alpine valleys as the altitude ranging from 550 m to 4868 m, was an important biodiversity conservation area and ecological barriers of the upper Yangtze River. The annual precipitation was about 560.8 mm and distributed unevenly. BLJW was also well-known for its varieties of rare and endangered plants and state key protection wild plants, such as *Davidiainvolucrata* Bail, *Metasequoia glyptostroboides*, *Cathaya*, *Emmenoptery shenryi* Oliv, *Cercidiphyllaceae*, *Acer paxii* Franch, *Toonaciliata* Roem. Furthermore, some medical plants and rare animal also distributed widely (e.g. *Angelica sinensis*, *Codonopsis pilosula*, *Rheum palmatum* L, *Hedysarum polybotrys* Hand. Mazz, *Radix bupleuri*, and *Ailuropoda melanoleuca*, *Rhinopithecus roxellana*, *Antidorcas marsupialis*, *Macaca arctoides*, *Moschus moschiferus* Linnaeus, *Elaphodus cephalophus*) (Tang *et al.*, 2005; Xie *et al.*, 2015). In addition, there were several reserves and forest districts in BLJW for biological protection, such as, Baishuijiang National Nature Reserve (BSR), Duoer Nature Reserve (DNR), Axia Nature Reserve (ANR), Dieshan Mountain Forest District (DMF), Yuhe Nature Reserve (YNR), Chagangliang Forest District (CFD), etc.



**Figure 1** Location (a) and land use types (b) of the BLJW in 2010

### 3 Data and methods

#### 3.1 Habitat quality assessment via InVEST model

Habitat loss and fragmentation was considered as the main reason of plant biodiversity loss (Wilson *et al.*, 2016), and the biodiversity pattern in medium and larger scale can be estimated by integrated analysis of habitat maps with threat factors (Fahrig, 2003; Tallis *et al.*, 2013; Wilson *et al.*, 2016), InVEST model introduced the habitat quality as a proxy for biodiversity assessment (Polasky *et al.*, 2011; Tallis *et al.*, 2013). Habitat quality was a function determined by four factors (e.g. each threat's relative impact, the relative sensitivity of each habitat type to each threat, the distance between habitats and sources of threats, and the degree to which the land was legally protected (Tallis *et al.*, 2013; Chen *et al.*, 2016). Generally, habitat quality degradation was caused by the intensity of nearby land-use expansion related to human activities and land use/cover change (Xu *et al.*, 2013; Liang and Liu, 2017). At the pixel scale, a pixel cell threat level was translated into a habitat quality using the total threat level and a half saturation function. The

specific calculation formula was listed as follows:

$$Q_{xj} = H_j \times \left[ 1 - \left( \frac{D_{xj}^z}{D_{xj}^z + k^z} \right) \right] \quad (1)$$

$$D_{xj} = \sum_{r=1}^R \sum_{y=1}^{Y_r} \left( W_r / \sum_{r=1}^R W_r \right) r_y i_{rxy} \beta_x S_{jr} \quad (2)$$

where  $Q_{xj}$  is ecological habitat quality value of land use type  $j$ ,  $H_j$  is a habitat quality score that ranges from 0 to 1, where non-habitat land-use types are given a score of 0 and perfect habitat classes are scored 1,  $D_{xj}$  is the total threat level in grid cell  $x$  with land-use type  $j$ , and  $k$  is the half saturation constant (Tallis *et al.*, 2013; Liang and Liu, 2017; Sun *et al.*, 2015),  $Z$  is a constant.  $R$  is the number of ecological threat factor,  $W_r$  is the threat weight that relates destructiveness of a degradation source to all habitats,  $Y_r$  is the set of grid cells on  $r$  raster map,  $y$  is all grid cells,  $r_y$  is raster map  $r$ ,  $i_{rxy}$  is the distance function of habitat quality and ecological threat factor,  $\beta_x$  is the level of accessibility in grid cell  $x$ , where 1 indicated complete accessibility;  $S_{jr}$  is the sensitivity of land use type  $j$  (habitat type) to the ecological threat factor  $r$ . Here, the accessibility of each land use type was equal according to the national laws without considering of land reserve difference in the BLJW. At the same time, the values of relative sensitivity  $S_{jr}$  of each habitat type to each ecological threat ranged from 0 to 1, where 1 represented high sensitivity to a threat and 0 represented no sensitivity to a threat (Xu *et al.*, 2013; Liang and Liu, 2017). According to the natural system conditions and the current situation of BLJW, urban, rural residential areas, population density, cropland, roads, ecological risk source is selected as the main ecological threats (Table 1). In our study, primary roads refer to the national highways and provincial roads, the secondary roads refer to county and township roads, respectively; while the ecological risk source including landslide, debris flow, soil erosion, earthquake and drought. Then, the maximum effected distance of each ecological threat of urban, rural residential area, cropland, population density, primary roads, the secondary roads and ecological risk source are 6.0, 2.5, 1.5, 3.5, 2.5, 0.5, and 3.0 km, respectively. And the weight of each ecological threat of urban, rural residential area, cropland, population density, primary roads, the secondary roads and ecological risk source are 0.8, 0.4, 0.6, 0.3, 0.6, 0.5 and 1 according to the previous relative research results (Tallis *et al.*, 2013; Xu *et al.*, 2013; Sun *et al.*, 2015; Wilson *et al.*, 2016; Zhang *et al.*, 2017; Liang and Liu, 2017) and the users' guide of InVEST model (Tallis *et al.*, 2013), respectively. In this paper, Landsat TM/ETM+ images (nominal resolution is 30 m×30 m, acquired on 9/1990 and 10/2010) are processed using the ENVI 4.8 software, which involves geometric correction, image enhancement and supervised classification (Du *et al.*, 2016). Based on this, land cover dataset is obtained by supervised classification and visual image interpretation based on experimental knowledge and field observation, and land-use types are classified as agricultural land (AL) (including farmland, vegetable plots, orchards, and nurseries), forest land (FL) (including forest, spinney, open woodland, other forest), shrubs, grassland (GL) (including high, medium, low coverage grassland), built-up land (BL) (including residential, commercial, and industrial land together with public transportation corridors, and construction sites), water

areas (WA) (including rivers, aqueducts, lakes, ponds, and reservoirs), and unused land (UL) (including salinized land, derelict land, bare land and low-coverage grassland with vegetation cover <5%). In addition, a total of 200 points are randomly selected to verify the precision of classification through field surveys, while the topographic map and images from Google earth with high spatial resolution are used as the accessorial materials, and the overall accuracies of the years 1990 and 2010 are both larger than 84%. Meanwhile, local residents are also interviewed about the land use history, and land transformation information provided by the local government is analyzed to understand and explain the factors responsible for triggering landscape changes. Finally, the other detailed input data for InVEST habitat quality model in the study are prepared. At the same time, due to different vegetation types had provided different habitat, the differences of vegetation types should be considered to the weight of habitat quality, respectively (Table 1).

**Table 1** Sensitivity of different land use types to different ecological threat factors

Code	Land use types	Habitat	Ecological threat factors						
			Primary roads	Secondary roads	Urban	Rural residential area	Cropland	Population density	Ecological risk source
11	Forestry	0.9	0.9	0.7	0.6	0.5	0.3	0.7	0.25
21	Bush	0.8	0.8	0.6	0.5	0.4	0.4	0.6	0.36
31	Grassland	0.6	0.7	0.5	0.3	0.2	0.5	0.5	0.44
41	Cropland	0.3	0.5	0.6	0.5	0.4	0	0.8	0.57
51	Rivers and lakes	0.9	0.75	0.65	0.8	0.7	0.1	0.5	0.15
61	Urban	0	0	0	0	0	0	0.95	0.6
71	Rural residential area	0	0	0	0	0	0	0.85	0.6
81	Transportation	0	0	0	1	1	0	0.4	0.6
91	Unused land	0.01	0.2	0.2	0.1	0.1	0.1	0.3	0.4

3.2 NPP and landscape structure indexes

Generally, the decline in NPP could indirectly reflect vegetation degradation and biodiversity reduction (Liu *et al.*, 2015; Lausch *et al.*, 2016) in the farming-grazing transitional region from the northern subtropical zone to the warm-temperate zone. BLJW was just located in this region of China, so NPP of BLJW could reflect the vegetation ecosystem production capacity, quality, elastic and biodiversity (Liu *et al.*, 2015). Secondly, landscape structure index (*LSI*) referred to the landscape structure situation and played an important role in evaluating regional ecosystem sustainable development ability and landscape diversity. Generally, *LSI* could be calculated by the formulas listed below (Zhao, 2012; Xie *et al.*, 2017):

$$LSI_x = 1 - (aCi + bNi + cFi)$$
 (3)

$$Ci = \frac{ni}{Ai}$$
 (4)

$$N_i = 0.5 \sqrt{n_i/A} \times \frac{A}{A_i} \quad (5)$$

$$F_i = 2 \ln \left( \frac{P_i}{4} \right) \ln A_i \quad (6)$$

where  $LSI_x$  is landscape structure index,  $C_i$  is landscape fragmentation index,  $N_i$  is landscape separation index,  $F_i$  is landscape fractal dimension index,  $a$ ,  $b$  and  $c$  represent the weights of the three indexes,  $P_i$  is the perimeter of patch  $i$ ,  $n_i$  and  $A_i$  are the number of patches in the landscape and total landscape area of patch type  $i$ .

### 3.3 Plant Biodiversity Index ( $BI$ )

Here  $Q_{xj}$ ,  $NPP$  and  $LSI$ , which refer to regional biological habitat quality, vegetation production capacity and landscape diversity, respectively, are used to obtain the comprehensive index of plant biodiversity spatial patterns, and can be expressed as the biodiversity index ( $BI_x$ ):

$$BI_x = Q_{xj} \times \beta_1 + NPP_x \times \beta_2 + LSI_x \times \beta_3 \quad (7)$$

where  $BI_x$  is plant biodiversity comprehensive index;  $\beta_1$ ,  $\beta_2$  and  $\beta_3$  are the weights of  $Q_{xj}$ ,  $NPP_x$  and  $LSI_x$ , respectively, which is calculated by Analytic Hierarchy Process ( $AHP$ ). Based on the comprehensive consideration of the influence degree of each index of biodiversity pattern of BLJW and the previous researches to construct the comparison matrix, to calculate and obtain the maximum eigenvalue of comparison matrix (value of 3.09) and its feature vector, the value of CR was  $0.042 < 0.1$  through the consistency check.

## 4 Results and analysis

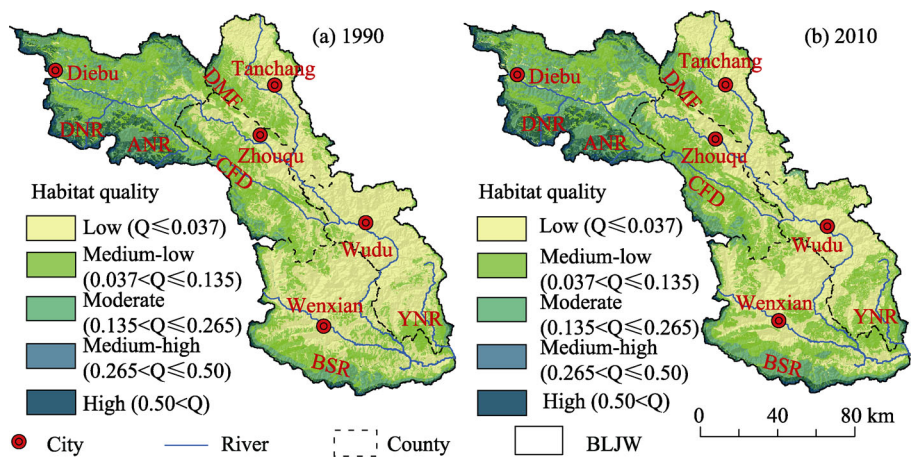
### 4.1 Habitat quality in the BLJW

As shown in Figure 2, the spatial distribution of habitat quality was changed obviously in BLJW. The low habitat quality area distributed widely and concentrated in the valleys of the BLJW between Zhouqu-Wudu-Wenxian counties, most of Tanchang County, and the northern part of Wenxian County, where human activities were relatively frequent and intensive. The higher habitat quality areas were mainly distributed in the mountain forest and nature reserves, such as Baishuijiang National Nature Reserve. On the administrative unit, habitat quality can be ranked as: Diebu County > Wenxian County > Zhouqu County > Tanchang County > Wudu District. During the period of 1990–2010, the habitat quality tended to increase, and the area proportion of high habitat quality increased from 20.2% to 25.4% while the area proportion of low habitat quality decreased gradually (Figure 2).

### 4.2 Characteristics of $LSI$ and $NPP$ in BLJW

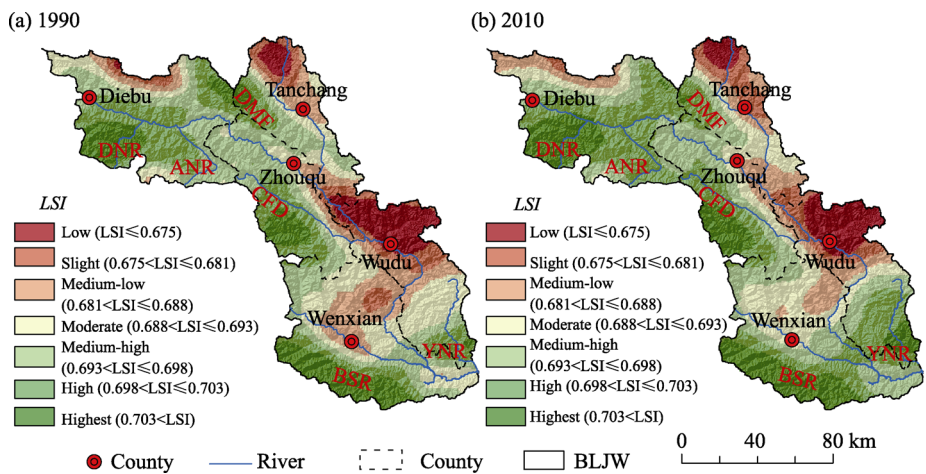
The average annual value and the highest value of  $NPP$  in BLJW were  $500.59 \text{ gCm}^{-2}\text{a}^{-1}$  and  $1147.68 \text{ gCm}^{-2}\text{a}^{-1}$  from 2001 to 2010, respectively. The low  $NPP$  areas located in the BLJ valley, hilly area, and alpine mountainous area which elevation was above 3500 m, while the high  $NPP$  areas were mainly distributed in Diebu County, Wenxian County, Duoer-





**Figure 2** The spatial distribution of habitat quality in BLJW in 1990 (a) and 2010 (b)

Axia Nature Reserve (DNR-ANR), Chagangliang Nature Reserve (CNR), Dieshan Mountain Forest District (DMF) and Gaolou Mountain. On the other hand, the distribution pattern of *LSI* was similar with that of habitat quality and *NPP*. The areas with low *LSI* mostly located along Bailongjiang and its tributaries, the northwestern part of Tanchang County and the northern mountainous areas of Diebu County (such as Majie township, Anhua township, Hanwang township, Liangshui township, etc.), while the high *LSI* area distributed in the nature reserve and forestry areas (Figure 3). The average annual value of *LSI* in the BLJW had increased from 0.692 in 1990 to 0.696 in 2010.



**Figure 3** The spatial distribution of *LSI* in BLJW in 1990 (a) and 2010 (b)

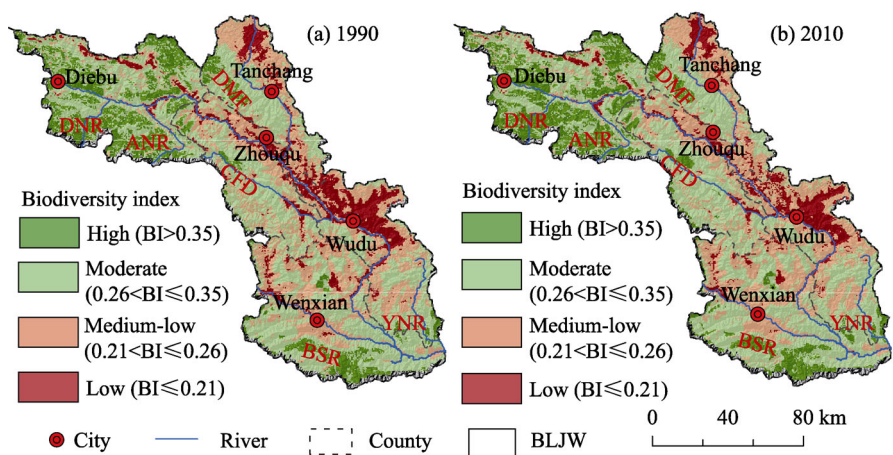
**4.3 Change of biodiversity index (*BI*) in the BLJW**

Table 2 and Figure 4 display the *BI* change in BLJW from 1990 to 2010. During 1990–2010, the mean *BI* of BLJW increased from 0.28 in 1990 to 0.29 in 2010. The high biodiversity area increased obviously and its area proportion changed from 14.13% to 17.15%. The area

proportion of medium-low and lower *BI* decreased which indicated that the biodiversity restoration in BLJW was still a huge challenge and needs to be paid more attention in the future. Spatially, the areas with high *BI* were mainly concentrated in the nature reserve areas, the middle and subalpine forest areas (Figure 4) which usually had a high vegetation coverage, better habitat quality, richer species, and were the key areas of rare animals and plants, such as *Ailuropoda melanoleuca*, *Rhinopithecus roxellana*, *Antidorcas marsupialis*, *Elaphodus cephalophus*, *Acer paxii* Franch, *Davidia involucrata* Baill, *Metasequoia glyptostroboides*, *Cathaya*, *Toona ciliata* Roem. The moderate *BI* areas mainly distributed in forest, shrub and grassland, and accounted for 45.18% of the watershed area, while the medium-low biodiversity area accounted for 28.88%. The proportion of low biodiversity was up to 8.79%, and mainly concentrated in farmland, mining area, urban and rural areas, disaster prone area and bare rock zones (Table 2 and Figure 4). Generally, as to the areas with lower *BI* value, the ecosystems characterized with less species, higher landscape fragmentation, fragile ecological environment, and/or frequent and intensive human disturbance.

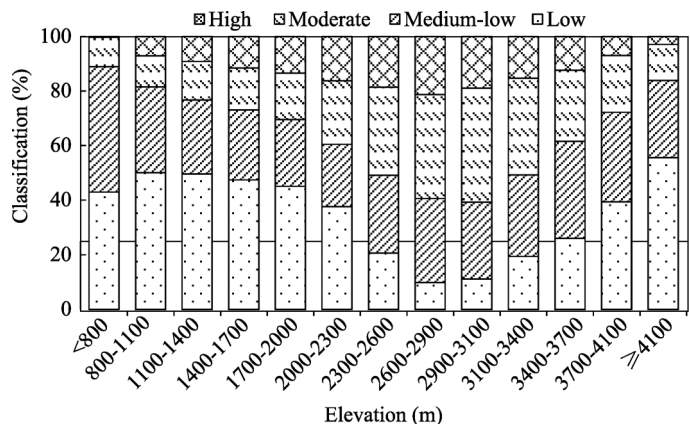
**Table 2** Area proportion of different biodiversity classifications in BLJW in 1990 and 2010

	1990		2010	
	Area (km <sup>2</sup> )	Percentage (%)	Area (km <sup>2</sup> )	Percentage (%)
Low ( $BI \leq 0.21$ )	2099	11.39	1620	8.79
Medium-low ( $0.21 < BI \leq 0.26$ )	5512	29.90	5325	28.88
Moderate ( $0.26 < BI \leq 0.35$ )	8219	44.58	8330	45.18
High ( $BI > 0.35$ )	2605	14.13	3161	17.15



**Figure 4** The integrated assessment of plant biodiversity spatial pattern in BLJW in 1990 (a) and 2010 (b)

Figure 5 showed that the high and moderate biodiversity areas mainly concentrated in the altitude range of 1400–3500 m, while the low biodiversity areas concentrated under the altitude of 1700 m or the higher altitude zone. At the same time, field surveys also found that the area of increasing biodiversity index mainly belonged to ecological engineering restoration area, natural protection and forestry areas, particularly the areas of Grain for Green Project, Natural Forest Protection Project, Shelter Forest Project in the middle and upper reaches of the Yangtze River, while the area where biodiversity decreasing located in the region with



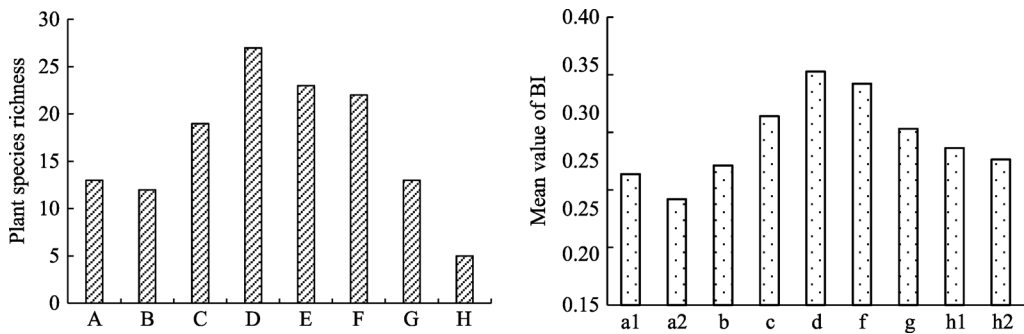
**Figure 5** The altitude distribution of different biodiversity classification in BLJW

intensive and frequent human activities. Moreover, the areas with plant biodiversity improvement were larger than that of plant biodiversity reduction (or degradation), suggesting that the ecological environment and biodiversity were getting better in the BLJW recently.

## 5 Discussion

### 5.1 Spatial pattern of plant biodiversity change in BLJW

Plant biodiversity has obvious spatial pattern variations in BLJW, and the lower biodiversity areas mainly distributed in farmland, urban and rural areas, bare land and the lower coverage grassland, while the high and high-moderate areas mainly distributed in the National Nature Reserve and forestry area. Specifically, the higher plant biodiversity area mainly distributed in six sub-regions: BSR, DNR, ANR, DMF, YNR, CFD and the upper reaches of Boyu River. This result was similar to the report of priority areas for Chinese biodiversity conservation published by Ministry of Environmental Protection of China, which had pointed out that BLJW was an importance part of biodiversity conservation priority region of Minshan-Northern Hengduan Mountains (Xie *et al.*, 2017). In addition, it was similar to the field survey and observation and some previous research results (Guo *et al.*, 2003; Ding *et al.*, 2006; Zheng *et al.*, 2014; Xie *et al.*, 2017). Firstly, four field investigations were carried out in September 2011, August 2012, June 2013 and July 2014, respectively, for better understanding the changes of land use, plant biodiversity, ecological restoration, vegetation coverage and pattern, geographical landscape and natural disasters, etc. The results of the survey work showed that the plant species of evergreen broad-leaved forest, broad-leaved deciduous forest, evergreen and deciduous broad-leaved mixed forest were richer than other vegetation types (Figure 6), the BSR was regarded as the most abundant area of species diversity. And then, the trend of mean value of BI was similar to that of plant species richness of quadrat survey in BLJW by comparing Figure 6. Secondly, some previous research results of biodiversity sample plot survey or biodiversity quadrat investigation in BLJW (e.g. Guo *et al.*, 2003; Qiu *et al.*, 2007; Ding *et al.*, 2006; Zheng *et al.*, 2014) and local flora, scientific report (e.g. national list of the higher endangered wild plant and animal species, scientific report of Baishuijiang National Nature Reserve (BSR)) also showed that high species richness appeared in the reserves and mountain forest at elevations of 1000–3200 m. For



**Figure 6** Plant species richness of quadrat survey (left) and plant BI (right) in BLJW

Note: in the left figure, A: Herb species of grass communities, B: Shrub species of shrub communities, C: woody plant species, D: deciduous broad-leaved forest with 700–1100 m elevation, E: evergreen broad-leaved forest, F: deciduous broad-leaved forest at 1300–1900 m elevation, G: evergreen and deciduous broad-leaved mixed forest, H: broad-leaved and coniferous mixed wood, coniferous forest

example, the plant species richness were 943 and 1278 species in ANR and BSR, respectively, while woody plants were 59 series and 269 species in the dry valley, 115 series and 565 species in the forestry area of middle-upper reaches of BLJW (Guo *et al.*, 2003; Qiu *et al.*, 2007; Ding *et al.*, 2006; Zheng *et al.*, 2014).

In the right figure, a1 is mountain meadow, a2 is alpine meadow, b is shrub, c is broad-leaved forest, d is evergreen broad-leaved forest, f is evergreen and deciduous broad-leaved mixed forest, g is coniferous and broad-leaved mixed forest, h1 is deciduous coniferous forest, and h2 is coniferous forest.

## 5.2 Feasibility of InVEST with landscape pattern indexes for medium/larger scale plant biodiversity assessment

Traditional approaches like biodiversity monitoring had made significant steps forward to quantify and evaluate biodiversity at many scales but still, these methods were limited to comparatively small areas (Lausch *et al.*, 2016; Murguía *et al.*, 2016; Guo *et al.*, 2017; Vihervaara *et al.*, 2017). And then, it was necessary to map the range or occurrences of elements (e.g. species, habitats) for managers to understand the patterns of distribution and richness of a certain larger landscape, individually and in aggregate (Tallis *et al.*, 2013). Integration of ecological model with satellite images may provide a useful solution for medium/large scale to overcome these shortcomings, especially in the visualization and mapping of biodiversity spatial pattern, protected areas planning. So, many studies dedicated to the application of biodiversity model (such as InVEST habitat quality model) and earth observation technology (such as remote sensing technology, radar and high-resolution X-ray microtomography, etc.) in biodiversity conservation and research (John *et al.*, 2008; Urbazaev *et al.*, 2015; Lausch *et al.*, 2016). Recently, InVEST habitat quality model was widely used to analyze the biodiversity status and to reveal its spatial and temporal change at the medium/larger scale (e.g. at the watershed scale by Bai *et al.*, 2011, Terrado *et al.*, 2016; at the national scale of China by Ouyang *et al.*, 2016, Italy by Sallustio *et al.*, 2017, etc.), because it could combine the information on LUCC and habitat threats to evaluate habitat quality of plant biodiversity with a lower basic data demand (Tallis *et al.*, 2013). Many empirical studies proved that habitat quality could reflect regional biodiversity and the validity

of InVEST habitat quality model (Schindler *et al.*, 2013; Liang and Liu, 2017). On the other hand, earth observation technology was widely applied to biodiversity monitoring at the regional spatial scale directly (e.g. GPS tracking, thermal imaging) or indirectly (by detecting the landscape pattern, ecological change, functional vegetation diversity, etc.). Landscape patterns could provide the foundation for ecological processes, the changes in landscape patterns will affect habitat quality inevitably (Guiomar *et al.*, 2015). Landscape structure index (*LSI*) here was used as the integrative indicators at the landscape scale to assess landscape pattern and the state of biodiversity, and to reveal the impact of land use change on biodiversity. Meantime, *NPP* could reflect the terrestrial ecosystems quality (Li *et al.*, 2013; Guo *et al.*, 2017) and production, was an important index of functional vegetation diversity (Zhang *et al.*, 2014; Liu *et al.*, 2015; Wang *et al.*, 2016; Schulze *et al.*, 2018). For example, John *et al.* (2008) predicted plant species richness and diversity based on remote sensing products (e.g. GPP and EVI) in the semi-arid region of Inner Mongolia. Kooistra *et al.*, (2008) had assessed and predicted biodiversity by assimilating of *NPP* derived from imaging spectrometer data into a dynamic vegetation model. In this study, we integrated habitat quality, *NPP* (via CASA model) and *LSI* to get a comprehensive biodiversity index to demonstrate the spatiotemporal change of plant biodiversity in BLJW. And then, the result showed that the spatial distribution of biodiversity was clearly seen in BLJW, and was similar to the pattern based on plot survey or biodiversity quadrat investigation in BLJW (Guo *et al.*, 2003; Ding *et al.*, 2006; Zheng *et al.*, 2014). Accordingly, this integration of InVEST with landscape pattern indexes was appropriate and useful in the BLJW, and the methods could be applied to the similar area with poor data of species and biological indicators at the medium/large scale mountainous area, although there was some possible uncertainty.

### 5.3 Limitations (/uncertainty) and outlook

Although integration of InVEST-habitat quality model with landscape pattern indexes was a helpful way when species distribution data was poor or mixed habitat types co-exist in study sites (Polasky *et al.*, 2011), many challenges and limitations still remain in its practical application. Firstly, the InVEST-habitat quality model had a little consideration of the site conditions for bio-community, such as climate, soil, water-energy condition, boundary constraint, the habitat difference of vegetation (Zheng *et al.*, 2014). Moreover, current researches mostly relied on the expert's knowledge and parameters of InVEST model datasets (Baral *et al.*, 2014; Terrado *et al.*, 2016) when applying InVEST-habitat quality model, such as the maximum effective distance and weights of each ecological threat factor. Moreover, the parameters of different areas should be different, and the parameterization would be deeply affected by the expert's subjectivity, it still needed to be improved in the future. In this paper, the parameters used were mainly from field investigation and previous research results in the similar areas, so it might lead to some uncertainty and faultiness of habitat quality. Hence, it was needed to be improved urgently in the future. Secondly, the landscape indexes also had not considered the difference of vegetation and their own biodiversity significance. For example, the same landscape metrics of different vegetation usually had same values due to their same patches, but its corresponding biodiversity might be different. Thirdly, this study had paid less attention to the other biotic entities (such as animal biodiversity, insect biodiversity, even individual and community diversity scale) except plant bio-

diversity. Not surprisingly, assessing and mapping the spatial and temporal variation of biodiversity was a challenging topic, especially in the complex regions which had no comprehensive ecological monitoring data. In spite of this, this study had successfully provided and demonstrated an example to quantify plant biodiversity spatial pattern at the landscape scale by integration of the ecological model, GIS and landscape ecological ideas, and emphasized and mapped the biodiversity change on the raster scale, not the administrative unit. Thus, in order to accurately and effectively assess and map the biodiversity change, field observation (such as quadrat survey of species, local background investigation, etc.) and earth observation (including satellite tracking, remote sensing) were not only a long time task, but also should be combined with model simulation in the future research in further study (Nagendra *et al.*, 2013; Turner *et al.*, 2015; Murguía *et al.*, 2016; Lausch *et al.*, 2016; Guo *et al.*, 2017).

#### 5.4 Implications for regional plant biodiversity assessment and management

Spatial assessment and mapping of biodiversity played a vital role in identifying key areas for conservation and establishing protection priorities. Our study found that plant biodiversity increased along the restoration area of ecological engineering, nature reserve and forestry areas, and decreased in the areas with intensive and frequent human activities and geo-disasters, which was typically characterized in the most fragile mountainous areas in western China (e.g. Qinling Mountains by Zhang *et al.*, 2017; Minshan Mountains by Li *et al.*, 2017). This not only showed that ecological restoration, land use and cover change, population and human activities profoundly influenced the distribution of plant biodiversity, but also would be some profound implications for plant biodiversity conservation and sustainable development of the mountainous areas in China. For the regional sustainable development of BLJW, integrated management and optimization of human activities and land use planning should be carried out as soon as possible, such as mining management and road construction, Ecological Red Line implementation, expansion of protection areas and its networks. Secondly, more long-term observation measures and application-oriented research should also be carried out for the conservation planning and plant biodiversity management, particularly integration earth observation and taxonomic, structural and functional biodiversity (Lausch *et al.*, 2016). And then, field survey (e.g. biodiversity baseline inventories and monitoring) and experimental studies will be great help on the implementation of conservation strategies (Gong *et al.*, 2014; Ma *et al.*, 2017). Moreover, to carry out the vegetation restoration and ecological reconstruction (such as integration of biological and (or ecological) engineering, farming engineering, forming the trinity target of soil and water conservation), and to reduce the ecological risks and disasters of irrational human disturbance, would be vital to the realization multiple-win of the economic, social and ecological protection and for the sustainable development in the hilly area of China.

## 6 Conclusions

This study provided and demonstrated the spatial and temporal pattern change of biodiversity in BLJW of western China. The spatial pattern of plant biodiversity was obviously changed in BLJW, the areas with higher plant biodiversity were 3161 km<sup>2</sup> and mainly distributed in the southern and southwestern BLJW with mid-high mountain forest, while the poor plant biodiversity areas distributed in the river valleys with intensive and frequent hu-

man activities, such as cultivated area, urban and rural areas. The mean plant biodiversity of BLJW increased from 0.28 to 0.29 during the period of 1990–2010, though some degradation happened in some subareas, especially in the poor biodiversity service areas.

Considering the complex mountain environment system, frequent natural disasters and shortage of long-term field monitoring data in BLJW, this study tried to establish an evaluation method of plant biodiversity spatial pattern with the integration of habitat quality, *NPP* and landscape pattern indexes, and to demonstrate the spatiotemporal change of plant biodiversity at the raster cell scale. It showed that this comprehensive index of integration analysis was useful and can be applied at the regional scale. Yet, due to the complexity of biodiversity mechanism, the ecological characteristics difference of selected indexes as well as complex natural system of BLJW, it might still lead to some uncertainty and demerits. In the future, how to combine field quadrat investigation and satellite images with spatial analysis to assess the spatiotemporal change of plant biodiversity need to be paid more attention, and more case studies need to be carried out to improve the methods.

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