

# The emerging cross-disciplinary studies of landscape ecology and biodiversity in China

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**Abstract:** The spatiotemporal landscape heterogeneity implies multiple biodiversity mechanisms across scales, and the cross-disciplinary studies between landscape ecology and biodiversity are becoming a new research field in China. This paper briefly reviews the development of the field by comparing papers published in international journals and Chinese journals; then it investigates the differences in the trends and focuses between international and Chinese studies. We also introduce several study areas that have emerged over the last 10 years in this field, including metacommunity assembly, landscape genetics, biodiversity and ecosystem service relationship, and landscape planning for biodiversity conservation. The major advances emerging in this field in China over the past 5 years can be classified into six subject areas: 1) effects of urban landscape and urbanization on biodiversity; 2) altitudinal patterns of biodiversity in mountain landscapes; 3) effects of topographic heterogeneity on plant community assembly and species coexistence; 4) impacts of landscape patterns and processes on animal behaviors; 5) forest fires and spatiotemporal patterns of vegetation responses; and 6) landscape ecology applications in natural conservation planning and design. In an attempt to promote cross-field studies between geography and ecology, this special issue collected 10 research articles, involving multiple landscape types and biological assemblages, in order to explore the interaction between landscape features and biodiversity. We anticipate that the future development of this active front will be primarily driven by the application of novel information techniques and the realistic demands of sustainability issues, in addition to answering scientific questions cross scales.

**Keywords:** landscape ecology; biodiversity; cross-disciplinary study; frontiers; progresses

## Introduction

The spatiotemporal heterogeneity of a landscape determines its close relationship with biodiversity (Tscharntke *et al.*, 2012). Since the 1980s, landscape ecology has developed rapidly as a cross-field between geography and ecology (Wu *et al.*, 2006). Meanwhile, the mechanisms underlying species coexistence and biodiversity maintenance have also become an important research area in ecology (Rohde, 1992). Although the developments of these two

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fields had been relatively independent during their early stages, nature conservation actions over the world have manifested that landscape is an indispensable part of biodiversity (Margules and Pressey, 2000; Hoorn *et al.*, 2010), and landscape ecology has ecological and evolutionary significance in biodiversity studies (Naveh, 1994). In the 21st century, the large increase in multi-scale ecological researches has provided an unprecedented opportunity to integrate the two fields with multiple cross-areas emerging between them. This has considerably promoted the applications of landscape ecology and biodiversity theory in species conservation and the sustainable management of natural resources (Cumming, 2007; Leite *et al.*, 2013; Burel *et al.*, 2013; Turrini and Knop, 2015).

The landscape ecology theory of pattern-process interaction provides an intuitive framework for multi-dimensional and multi-scale studies of biodiversity (Tschardt *et al.*, 2012). Habitat heterogeneity is a critical driving force behind species composition changes, whereas habitat barriers and corridors have significant influences on population migration processes, which shape community assemblies and changes in species composition (beta diversity) (dos Santos *et al.*, 2015). Furthermore, ecological succession driven by landscape disturbance delineates the temporal niche differentiation for species coexistence (Vanschoenwinkel *et al.*, 2013). On the other hand, biodiversity researches provide information about biological responses to landscape structure, and an ecological and evolutionary perspective is critical if the functions of landscape patterns and processes are to be understood (Huston, 1999). Moreover, the scale in space and time is shared as a keystone concept by both biodiversity studies and landscape ecology in their theoretical frameworks (Willig *et al.*, 2003; Wu, 2004). In recent years, the theory of metacommunity assembly has taken in the idea of landscape scale and environmental heterogeneity in interpreting biodiversity patterns, and also presented a novel framework that integrates ecological, evolutionary, and spatial processes in landscape ecology (Leibold *et al.*, 2004; Spasojevic *et al.*, 2014).

China is one of the few countries with a mega biodiversity in the world, and characterized by its complex landscape (Qian and Ricklefs, 2000). Thus China possesses ideal conditions for studying the relationship between landscape ecology and biodiversity. Over the last 20 years, landscape ecology and biodiversity research have entered a period of vigorous development in China. However, the independent development of the two fields and their isolation from each other were obvious until recently. This special issue is based on the presentations given at the symposium “Mountain Landscape and Biodiversity Conservation” at the 12th International Conference of Ecology, held in Beijing in August, 2017. It has collected 10 research reports on the topic for the *Journal of Geographical Sciences*, a leading Chinese SCI journal that covers geographical subject areas. It aims to promote research in this field across China.

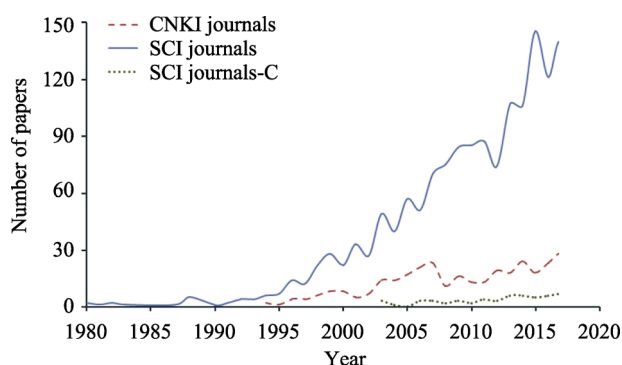
Partially as an editorial for this special issue, this paper, based on a search of the international journals included in the Science Citation Index (SCI, <http://apps.webofknowledge.com>) database and core Chinese journals included in the China National Knowledge Infrastructure (CNKI, <http://www.cnki.net/>), briefly covers the frontier scientific questions in the cross-field of landscape ecology and biodiversity, and summarizes the main research progresses by Chinese scientists in this field over the last 5 years. It also introduces the research content presented in this special issue. Finally, the future of cross biodiversity and landscape ecology studies is discussed.

# 1 Reference review for “landscape + biodiversity” studies

The ISI and CNKI reference databases were searched for landscape ecology and biodiversity studies that have been published by 20 July, 2018 in SCI journals and Chinese core academic journals. This search used a combination of search terms “landscape” and “biodiversity or diversity or species richness” in the title of papers published in SCI journals, and a combination of “景观” (means “landscape”) and “多样性 或 物种丰富度” (“diversity or species richness”) in the title of papers published in Chinese journals. As those SCI journals published in China are also collected by the Chinese database CNKI, we included the papers published in Chinese SCI journals merely in the statistics of SCI papers, rather than Chinese papers. The search collected a total of 1,577 papers published in 386 SCI journals since 1980, and 278 papers published in 163 Chinese core academic journals since 1994. Among the papers in the SCI journals, 67 papers since 2003 were contributed by authors from Chinese institutions. The following comparisons are based on the two reasonable, but obviously not complete samples, of researches from the two databases.

## 1.1 Increasing publications in English and Chinese

Although the result of the “landscape + biodiversity” search dated back to 1980, the number of papers before 1990 was very small. Publications on this theme in the SCI journals began to rise in the 1990’s, which stimulated similar studies in China, and papers of this type began to increase from 1994, but at a slower rate. Since 1995, international studies have accelerated, but similar studies in China have hardly increased over the past 10 years. No paper on this theme from Chinese institutes appeared in SCI journal until 2003. Since 2015, over 130 papers on this topic have been published annually in the SCI journals, although only 5–7 have come from Chinese institutes, and only 18–23 papers were published in Chinese journals, according to the CNKI database (Figure 1 and Table A1).



**Figure 1** Temporal change in publications on the “landscape + biodiversity” topic. SCI journal-C: papers in SCI journals contributed by authors from Chinese institutions

## 1.2 Landscape contexts and diversity studies

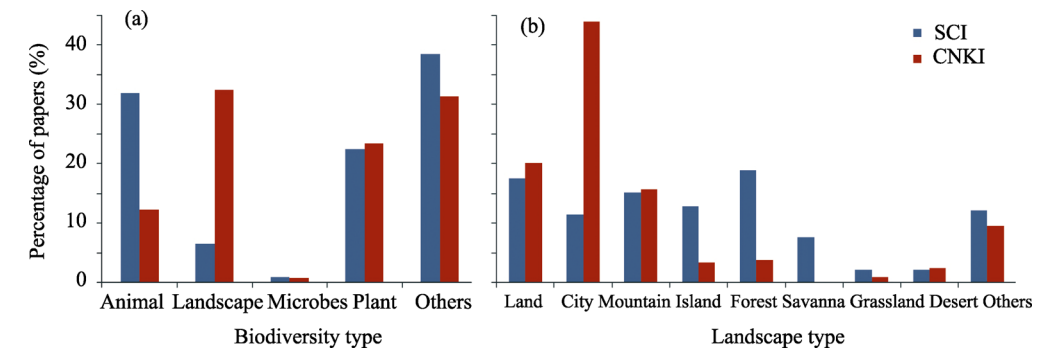
The composition of the biodiversity types involved and studies related to plant and microbes were comparable in the two samples, although plant studies were by far the largest group (Figure 2a and Table 1). A much higher percentage covered animal diversity in the SCI

journal papers than Chinese papers in the CNKI database (31.8% vs. 12.2%). However, landscape diversity constituted a much higher percentage in the CNKI sample than in the SCI sample (32.4% vs. 6.5%).

The general terms of “land” and “mountain” are top landscape contexts in studies found in the CNKI and SCI databases (>15%), whereas “grassland” and “desert” were minor (<5%) components in both samples. “city” and “urban” landscape occupied an overwhelmingly higher percentage in the CNKI sample than in the SCI sample (44% vs. 11%), while papers published in SCI journals showed a broader and more balanced distribution of subjects, with more attention being paid to the landscape contexts such as forest (18.9% vs. 3.8%), island (12.9% vs. 3.3%), and savanna (7.7% vs. 0.1%) (Figure 2b). Besides some biodiversity studies in the savanna context in CNKI journals, combination of landscape and biodiversity studies about savanna is almost an empty field.

**Table 1** The frequency distributions of “Landscape + biodiversity” papers published in SCI journals and CNKI journals, with respect to the corresponding biodiversity and landscape categories

Object	Category	SCI journal		CNKI journal	
		Number of papers	%	Number of papers	%
Landscape context	Land	276	17.5	56	20.1
	City	180	11.4	122	44.0
	Mountain	240	15.2	44	15.8
	Island	203	12.9	9	3.3
	Forest	298	18.9	11	3.8
	Savanna	121	7.7	1	0.3
	Grassland	33	2.1	3	1.0
	Desert	33	2.1	7	2.4
	Others	191	12.1	27	9.6
Biodiversity type	Animal	502	31.8	34	12.2
	Landscape	102	6.5	90	32.4
	Microbes	14	0.9	2	0.7
	Plant	353	22.4	65	23.4
	Others	606	38.4	87	31.3
Total		1577	100.0	278	100.0



**Figure 2** Comparisons of the percentage composition of papers published in SCI and CNKI journals that addressed (a) biodiversity type and (b) landscape type subject areas

## 2 Frontiers bridging biodiversity and landscape ecology

### 2.1 Landscape heterogeneity, metacommunity assembly, and species coexistence

The metacommunity theory considers the assemblage of animals or plants as a group of local communities, in a landscape with a set of spatially heterogeneous and separated habitat patches (Leibold *et al.*, 2004). The metacommunity theory adopts the hierarchical perspective of landscape ecology, and divides its objects into three spatial scales: microsite, locality (or patch), and region, which correspond to biological individuals, local communities, and the metacommunity. The dynamics among patches affects the species composition of the local communities, which therefore determines the spatial and temporal heterogeneity of the metacommunity structure (Hortal *et al.*, 2012; dos Santos *et al.*, 2015). The biological processes of dispersal, colonization, and extinction are integrated with rescue effect, mass effect, and source-sink syndrome, to interpret metacommunity assembly at multiple spatial and temporal scales. It is generally measured and compared using beta diversity indices, i.e., taxonomic, functional, and phylogenetic composition changes between local communities (Presley, 2010). Over the past 10 years, a metacommunity research area has emerged that encompasses: 1) impacts of habitat heterogeneity and connectivity on metacommunity structure and beta diversity patterns; 2) effects of ecological disturbance on interspecific niche replacement and community dynamics; and 3) responses of taxonomic, phylogenetic, and functional beta diversity to landscape heterogeneity (Logue *et al.*, 2011). This cutting edge topic has become a very active frontier in ecological theory studies, and a large number of related studies have been published in top ecology journals. These studies have mainly focused on subjects such as plankton communities, coral reefs, streams, and marshland. They have been characterized by small scale, explicit boundaries, and isolation, which have been used to explore the effects of space, environment, scale, and process on biodiversity (Moritz *et al.*, 2013). In China, studies on biodiversity patterns have been related to primary environmental gradients in mountains (Fang *et al.*, 2012), and the effects of habitat heterogeneity on plant diversity have been explored using a big plot approach (Ma, 2017). However, few studies have investigated the interactions between biodiversity and landscape pattern/process. So far, Chinese authors have contributed only six out of 473 papers on "metacommunity" in the Web of Science database; and in the CNKI database for Chinese papers, only seven papers have been published on the same topic.

### 2.2 Habitat fragmentation, gene flow, and landscape genetics

Landscape genetics crosses the boundaries between landscape ecology, molecular genetics, and biodiversity studies. It uses molecular markers and spatial analysis techniques to detect the spatial and environmental attributes of a landscape, to assess the effect of population isolation and genotype selection, and to reveal the spatial pattern of genetic flow and genetic structure (Manel *et al.*, 2003; Shen and Ji, 2010). In 2013, the journal *Molecular Ecology* released a special issue to summarize 10 years of progress in landscape genetics. As a multidisciplinary research field, landscape genetics focuses on effective population size and the gene flow of rare species, the potential pathways and barriers for species dispersal, and the effects of habitat fragmentation on the risk of local extinction (Manel and Holderegger, 2013). Driven by rapid improvements and innovations in research techniques, the frontiers

of landscape genetics was summarized as follows: 1) integrating broader spatial and temporal scales with finer landscape data that combine population properties and process information; 2) paying more attention to the landscape configuration; 3) considering the direction and source-sink dynamics of gene flow in the analysis of genetic connectivity; 4) using more complex and diverse statistical tools, such as Bayesian; 5) addressing neutral and adaptive genetic variations in response to spatial and environmental features of the landscape and 6) monitoring, evaluation, and management application of endangered species and foreign species (Bolliger *et al.*, 2014). In China, the study of landscape fragmentation, rare species population dynamics, and biological invasion has increased significantly over recent years, and has mainly focused on the flagship endemic species, such as the giant panda, golden monkey, Tibetan antelope, and Siberian tiger, or invasive species, such as *Eupatorium adenophorum*, pine wood nematode, whitefly, etc. However, previous studies have been rare in exploring the effects of landscape patterns and processes on population genetics (except Li *et al.*, 2017).

### 2.3 Landscape tradeoff/synergy between ecosystem service and biodiversity

Biodiversity forms the basis of ecosystem services at different levels and determines landscape multi-functionality. However, a synergy or trade-off relationship exists between biodiversity and specific ecosystem services (Mace *et al.*, 2012). Therefore, achieving the optimum compromise between biodiversity conservation and ecosystem services is a fundamental challenge for ecosystem management. In recent years, the search for solutions that coordinate ecosystem services and biodiversity conservation has become an active field in landscape ecology (Groot *et al.*, 2010; Cordingley *et al.*, 2015).

Landscape mapping and spatial analysis are important tools that are used to explore the distribution and dynamics of ecosystem services and biodiversity (Zhang and Fu, 2014). For example, landscape connectivity analysis provides a spatially explicit approach that can be used to understand the coupling and transmission between the demand and supply of ecosystem services (Mitchell *et al.*, 2013). The scenario-based simulation models for ecosystem services, represented by InVEST, have been widely applied to explore the role of land use change when coordinating and optimizing biodiversity conservation and various ecosystem services (Cordingley *et al.*, 2015). In 2012, the establishment of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) reflected the global value of obtaining the optimum compromise between biodiversity and ecosystem services (Díaz *et al.*, 2015). A novel space has emerged for the functional relationships between landscape ecology and biodiversity, which is built upon the theoretical and practical needs related to ecosystem services (Lavorel *et al.*, 2011). In China, the long-term monitoring of soil and water processes and ecosystem services on the Loess Plateau has led to significant achievements (Fu *et al.*, 2017). Furthermore, the application of the InVEST model has helped to assess ecosystem services across China (Zheng *et al.*, 2013; Xu *et al.*, 2017). However, research about the impact of landscape pattern processes on the interaction between biodiversity and ecosystem services is still very rare.

### 2.4 Landscape planning for biodiversity conservation

The focal object of nature conservation has shifted from the species to the ecosystem, and

then to the landscape and ecological processes. The principles of island biogeography and landscape ecology have been increasingly applied to species conservation planning, such as the evolution of the natural reserve planning principle from the SLOSS to FLOMS paradigm (Rösch *et al.*, 2015), and the application of gap analysis for protection (GAP), which is based on the overlay of spatial information of multiple landscape components, including roads, residential areas, and vegetation (Maiorano *et al.*, 2006).

Recently, more studies have investigated the mechanisms underlying the impacts of landscape attributes and processes on conservation. Studies on habitat fragmentation and population dynamics by Hanski (2015) revealed that the impacts of habitat loss and isolation on protected species differed in strengths and characteristic scales, whereas the study on habitat heterogeneity and population rescue effects by Matias *et al.* (2013) emphasized the supplemental effect of buffer zones on conservation. Studies on gene flow and effective populations that use molecular techniques to detect species dispersal pathways provide microscopic evidence that can be used to assess the functional connectivity of landscape patterns and the effectiveness of species conservation (Ribeiro *et al.*, 2011; Castillo *et al.*, 2016). Since 2000, based on a study into the response behavior of protected species to landscapes within and outside natural reserves, a large number of studies have begun to evaluate landscape design and to test the management pertinence and protection effectiveness of the existing conservation system. They have attempted to provide a scientific basis for the adjustment and improvement of protection efforts (Leverington *et al.*, 2010; Burton, 2012). In recent years, effectiveness evaluation of existing protection systems has been introduced and applied more often in China (Quan *et al.*, 2011).

### 3 Recent progresses in landscape and biodiversity studies in China

#### 3.1 Effects of urban landscape and urbanization on biodiversity

China has experienced the fastest urbanization in the world over the past 30 years. The impacts of this process on biodiversity, as well as the multi-level and multi-scale responses and the adaptation of organisms, has become a fast growing research field in Chinese landscape ecology (Normile, 2008; Zhao *et al.*, 2013b). Published studies have mainly focused on mega cities and their surrounding areas, such as the Bohai Rim, the Yangtze River Delta, and the Pearl River Delta region. Research subjects have included plants, fungi, birds, microbes, and aquatic organisms, etc. Research topics have expanded from species composition and community structure to physiological adaptations by species, genetic diversity, gene flow, and vegetation restoration. The main findings include the following.

(1) Over the past 10 years, the vegetation coverage in 32 major urban areas across China has declined by 85%, but the warmer climate, higher soil nutrient levels, and management by the city have promoted vegetation growth, which can account for 40% of the vegetation productivity that has been lost as a result of the reduction in vegetated areas (Zhao *et al.*, 2013b).

(2) The land cover gradient of urban built-up area-suburban area-outer suburban area constitutes a gradient of human activity intensity, which has had a significant impact on biodiversity composition (Meng *et al.*, 2015). The urban climate, soils, and human disturbance constitute a novel living environment. Studies on the flora and fauna in major Chinese cities,

such as Beijing, Nanjing, and Shenzhen, have found that some native species have adapted to the urbanized habitat conditions and artificial management. Furthermore, a large number of exotic species have also adapted to this new environment. They have, together, formed a unique urban species pool (Li *et al.*, 2016b; Sing *et al.*, 2016).

(3) There were significant differences in the physical and chemical properties of the soil under different land cover types in cities, which has had a significant influence on the biomass and functional diversity of soil microbes (Zhao *et al.*, 2013a). Soil nutrients and pH values determine microbial biomass, taxonomic composition, and functional diversity. They are also significantly impacted by the content and composition of heavy metals in soils.

(4) The invasion and adaptation of exotic species to the urban landscape, the key role of semi-natural vegetation in the conservation of biodiversity, and the construction of an ecological network in the urban landscape are attracting more attention (Yang *et al.*, 2009). However, at present, research on urban landscapes and biodiversity is mostly focused on application issues, such as the urban ecological environment assessment, whereas there have been little long-term monitoring of biodiversity dynamics and few studies on the biological responses to related environmental processes.

### 3.2 Altitudinal biodiversity patterns in mountain landscapes

The impact of mountain landscape heterogeneity on biodiversity patterns, especially along the altitudinal gradients, is an active research field in China.

(1) According to the data from around 1,400 plots of vegetation, woody plant species richness first rises and then decreases with increasing altitude on most mountains in China. The altitudinal pattern of plant species replacement was different from the latitudinal pattern, and local habitat heterogeneity has less than half the impact that climate factors do on the species richness of communities. However, regional differences in environmental history had a significant effect on the distribution of community species richness (Shen, 2012; Tang *et al.*, 2012).

(2) Scale-related difference in the climatic factors determines plant species richness. On the regional scale, the primary factor is the minimum temperature, whereas the energy-moisture balance primarily determines vegetation productivity on the landscape scale (Wang, 2012). On Dongling Mountain, Hebei Province, insect-plant mutualism and the competition for canopy plant species have significantly influenced the elevational species diversity pattern for understory plants, soil animals, and microbes (Jiang and Ma, 2015; Zhang *et al.*, 2015).

(3) The contributions of geomorphological heterogeneity and isolation to the maintenance of biodiversity in the Himalaya-Hengduan Mountains region. The Himalayan-Hengduan Mountains region is a global hotspot of biodiversity. By disentangling the roles of climate gradient, topographic complexity on species vicariance, Lei *et al.* (2015) found the regional climate stability dominated the extraordinarily high diversity and endemism in several songbird groups in the Himalaya and Hengduan Mountains. The mid-domain effect and habitat heterogeneity are also found critical for the altitudinal patterns of species diversity of birds, especially the small-ranged group, in this region (Wu *et al.*, 2014; Pan *et al.*, 2016). Yang *et al.* (2016a, 2016b) found that geomorphic isolation had a significant effect on plant diversity differentiation, and revealed that there was a prominent interaction between topography and



the monsoon on plant diversity patterns at the local and landscape scales. Han *et al.* (2016) showed that the effects of topographical isolation on the species composition of plant communities growing between the dry valleys of the Yalong River and the Dadu River were five times greater than the isolation effect due to Euclidean distance.

### 3.3 Effect of topographic heterogeneity on forest community assembly and species coexistence

Information from the China Forest Biodiversity Monitoring Network (CForBio), which is composed of 13 permanent forest plots that are 10–25 ha in area and spread across different climatic zones in China, showed that long-term monitoring and studies on forest community dynamics and species coexistence have been carried out at the landscape scale, including comparative and synthetic studies among plots (Feng *et al.*, 2016). There have recently been a number of internationally influential achievements, including those concerning the relationship between landscape pattern and biodiversity:

(1) The environmental heterogeneity dominated by topography is one of the two main mechanisms underlying plant community assembly and species diversity maintenance in tropical and subtropical forests. Although random effects play a major role in plant seedling density patterns, topographic heterogeneity (exposure and slope) determines the interspecific variation in large tree patterns because it affects the growth rate of seedlings (Hu *et al.*, 2012; Shen *et al.*, 2014).

(2) Topography has a species screening effect, which is shown by the greater effect of topography on functional diversity than the species diversity of the community. Furthermore, the functional attributes of the community also clearly changes as elevation and slope increases (Hu, 2014; Liu *et al.*, 2014).

(3) Genetic evidence shows that topographic relief has a stronger influence than spatial distance on the genetic structure of the tree population within the sample plots. The relative distribution of common species at different topographic positions can lead to genetic differentiation between sub-populations, which suggests that genotypes can adapt to corresponding habitat types (He, 2013; Wang *et al.*, 2014).

(4) The topography-related biodiversity maintenance mechanism has also been supported by national and global scale studies. Topographic complexity is thought to be a critical determinant of the high species richness within the genus *Rhododendron* in China (Yu *et al.*, 2015). However, the difference in the beta diversities within the global forest community species is mainly controlled by habitat differences, which are dominated by terrain heterogeneity among the sampling plots and the influence of local scale stochastic processes (De Cáceres *et al.*, 2012).

### 3.4 Impacts of landscape patterns and processes on animal behaviors

The effect of man-made landscape change on animal behaviors is also an important recent research area in China. It involves many biological assemblages, but researches have mainly focused on endangered species, especially the flagship species that need protection, such as the Giant Panda and the Siberian tiger. Publications about key species in Chinese core journals and SCI journals accounted for 8.4% and 42.1%, respectively, of all papers published

by Chinese authors in this field. Furthermore, birds, amphibians, and reptiles also account for a high proportion of the published papers. The main achievements of the research are as the following.

(1) There is a significant difference in the intensity of human activities between the inside and outside of nature reserves in Northeast China, and between the two sides of the China-Russia border. Human disturbance, mainly hunting, deforestation, and afforestation, have a profound impact on the spatial patterns for plant community structure and biomass. This has restricted the distribution and dynamics of wild boar and roe deer, and has had a corresponding effect on the individual behavior and population reproduction of tigers and leopards (Tian *et al.*, 2011, 2014).

(2) The wild giant pandas prefer high altitude needle and broad-leaved mixed forest and gently sloping habitats; human landscape elements, such as roads and villages, limit their population migration. The key variables for the giant panda migration model differ between seasons and sexes; and their home range marking behavior was mainly affected by tree size, species, and migration distance (Nie *et al.*, 2012; Qi *et al.*, 2012). The habitat quality assessment of giant panda populations in the Qinling Mountains and the optimization of the conservation area system revealed the spatial pattern and limiting factors affecting habitat quality, and the key corridors that are needed to maintain population gene exchange (Wu *et al.*, 2013; Liu *et al.*, 2015).

(3) There are spatial niche differences between the snow leopard, plateau wolves, rock sheep, and yaks, and Tibetan Buddhist temples have a protective effect on snow leopard habitats. The habitat overlap between rock sheep and the snow leopard makes the former a primary prey population for the snow leopard and this overlap affects the distribution of the prey population and the snow leopard habitat. However, climate change (rather than human activity) is expected to become the leading ecological stress factor for the snow leopard in the following decades (Li *et al.*, 2013, 2016a).

### 3.5 Forest fire and the spatiotemporal patterns of vegetation responses

The impact of forest fires on landscape pattern and biodiversity has attracted considerable attention in China, but previous studies have mainly concentrated on the Greater Hinggan Mountains and Southwest China. In 2015, the journal *Forest Ecology and Management* published a special issue on “Forest Fire in China”, which showed the distribution of forest fires and ecosystem responses in China (Adams and Shen, 2015). Major achievements in this field include the following.

(1) The magnitude of forest fires in the Greater Hinggan Mountains mainly depends on the weather, whereas fire intensity is mainly related to topography and vegetation structure (Fang *et al.*, 2015). However, fire intensity determines the post-fire regeneration mode of the forests. Self-restoration generally occurs at low fire intensity sites, whereas high fire intensity leads to the replacement of the community structure. The topography has little impact on the post-fire regeneration density, but determines the species composition of the community. Conifer species generally dominate post-fire regeneration on higher slopes, whereas the broad-leaved trees regenerate better on lower slopes (Liu, 2012; Cai *et al.*, 2013).

(2) In the middle Yunnan Plateau of Southwest China, most of the indigenous tree species

adopted regeneration strategies that were adapted to fire, such as seed serotiny, fire stimulated germination, and thick tree bark (Su *et al.*, 2015). The dominant species of the forest canopy remained stable before and after fires, which reflected the adaptability of the forest community to fire disturbance and the stability of the landscape structure. The density and species composition of the post-fire tree generation are clearly affected by topography, and the post fire regeneration patterns of the evergreen broad-leaved and coniferous tree species were significantly different. Species richness and spatial replacement of the herbaceous layer were mainly controlled by topography, the pre-fire community, and fire intensity (Han *et al.*, 2015).

### 3.6 Application of landscape ecology to the construction of a nature reserve system

Biodiversity conservation in China is traditionally based on the nature reserve system. In recent years, two important components, national parks and community conservation sites, have been added. Landscape ecology provides the necessary theoretical support for these nature conservation practices:

(1) In December, 2016, China built the first national park where the Siberian tiger and the Far East leopard were the core protection objects. The main scientific evidence supporting this achievement comes from the long-term comparative monitoring of the Sino-Russian border, investigations and research into the endangered statuses of the species, their spatial habitat patterns, and the major stress factors affecting the two endangered species. The results were selected by Springer Nature in 2017 as “180 annual outstanding papers that can change the world” (Wang *et al.*, 2016)

(2) Community protected areas have become an important component of the global nature conservation network in recent years. The Hengduan Mountains in Southwest China is one of the global biodiversity hotspot areas. In attempt to reduce intensifying landscape fragmentation and shrinking natural habitats due to human activities in this region, Li *et al.* (2009) produced a landscape planning design for the protection of endangered endemic species and the livelihoods of community residents. They explored the landscape approach to the coexistence of wildlife conservation and animal husbandry. This study provided critical scientific support for the successful establishment of “The Hoh Xil Natural World Heritage Site” in 2017.

(3) Environmental impact assessments and landscape optimization planning for tourism in nature reserves are being promoted in China. The processes mainly emphasize two aspects: 1) increasing landscape connectivity between nature reserves and inner core areas within each nature reserve; and 2) assessing the responses of different protected species to spatial habitat patterns and habitat quality in order to improve the spatial and structural attributes of the road network. The aim is to reduce road interference with core habitats within the protected area (Liu, 2011; Gong *et al.*, 2012; Wu *et al.*, 2013).

## 4 Content of this special issue

This special issue of *Landscape Ecology and Biodiversity* collected a group of ten case studies that focused on the interactions between biodiversity and landscape characteristics in order to reflect mainly the recent progress of Chinese studies in this field. Within this collec-

tion, the studies encompassed a variety of research areas, including trees, forest ecosystems, spiders and insects, vertebrates, and microbes, and they covered variant landscape contexts, such as mountain, urban, rural, and watershed areas. The study approaches include field investigations and experiments, mapping and statistics, and simulation models. These studies can be classified into four different types based on the science and technique questions addressed:

(1) Landscape heterogeneity and biodiversity patterns: Two papers in this collection explored the spatial patterns of plant and animal diversity at the landscape and broader scales, and estimated the effects of critical landscape features on plant diversity. Chen *et al.* (2019b) described the altitudinal patterns for plant  $\alpha$  and  $\beta$  diversity along a forest transect in a mountain landscape, and explored the effects of landscape heterogeneity in terms of gap disturbance and elevational gradient. Xu *et al.* (2019) explored the geographical patterns for species richness and the phylogenetic structure of plants in China using a mapping approach, and related diversity patterns to topographic complexity, which was treated as a landscape attribute. Hou *et al.* (2018) investigated the species richness patterns for spiders in an agricultural landscape and estimated the scale-related habitat effect on spider diversity.

(2) Biodiversity responses to landscape change: Apple *et al.* (2019) focused on the responses of plant functional traits and soil microbe composition to a heterogeneous (striped) periglacial landscape in northwestern USA and Chen *et al.* (2019a) detected the spatial and temporal variations in moisture content between soil and plants in a post-fire forest landscape. They discerned growth-form related variations in arid adaption by plant species. Field monitoring and experiments were used in these studies.

(3) Animal behavior in response to landscape variation: Three papers addressed the habitat selection and population dispersal issues faced by animals. After formulating habitat selection models for protected mammal species in mountain landscapes, Wu *et al.* (2019) tried to estimate the role of human disturbance (forest fragmentation) on the dynamics and distribution of optimal habitats for the targeted species, whereas Su *et al.* (2019) combined habitat and dispersal simulation models under a scenarios comparison framework, and identified a network of potential priority areas and corridors for the protection target. Yin *et al.* (2019) applied circuit theory to the multi species corridor detection problem in a heterogeneous landscape, and detected a potential network of dispersal corridors for species that varied in their environmental suitability.

(4) Landscape simulation and assessment of biodiversity and ecosystem service: Two simulation models for ecosystem service, InVEST and PANDORA, were applied by Gong *et al.* (2019) and Cheng *et al.* (2019) to estimate the change in biodiversity under landscape evolution scenarios driven by human land use. Both models have a module for the relationship between ecosystem service and biodiversity within the landscape context, while the robustness and rationality of the simulation results are to be tested by empirical studies.

## 5 Perspective on the cross-disciplinary study of landscape ecology and biodiversity

The relationship between landscape pattern, process, and biodiversity is a very active research field in international landscape ecology, but this research is relatively weak and scat-

tered in China. The reason maybe that landscape ecology in China has paid more attention to geographical processes, such as land use and urbanization, and had somewhat neglected biodiversity issues until recently. The development and application of theories and methods in this field is one of the urgent tasks for landscape ecology in China. Including this special issue, there are three ways that new research could be strengthened in the future.

(1) Actively applying new technology to improve our ability to collect and process landscape pattern-process and biodiversity information at broader spatial and temporal scales. These innovative techniques include networked ecological monitoring, combining multi-platform remote sensing tools with a variety of spectral information (laser, microwave, hyperspectral, and infrared), and genetic and functional properties analysis. They provide powerful tools and methods that can be used to explore the multi-scale relationship between biodiversity and landscape pattern and process.

(2) Landscape heterogeneity is a critical mechanism for maintaining biodiversity. Habitat differences and spatial isolation have been viewed as the core features of community assembly theory and biogeography. Therefore, landscape ecology needs to understand the ecological and evolutionary effects of landscape patterns and processes from the biodiversity perspective. Biodiversity research also needs to adopt the spatial understanding and analysis approach used in landscape ecology.

(3) Strengthening research on the relationship between biodiversity and landscape ecological services. Landscape heterogeneity provides a variety of spaces for the trade-off between different ecosystem services and the matching of supply and demand. It also provides the principles that are used to manage ecosystem service and biodiversity conservation. Coordination between biodiversity conservation and ecosystem services will be critical at the landscape level if the challenge of sustaining natural resources is to be met. This prospect is embodied in the creation of the Intergovernmental Science and Policy Platform for Biodiversity and Ecosystem Services (IPBES) and The Ecosystem and the Economics of Biodiversity (TEEB).

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# Appendix

**Table A1** The interannual change of numbers of papers published in CNKI journals, SCI journals, as well as those SCI papers contributed by Chinese institutes (SCI journal-C)

Publishing year	SCI journal	CNKI journal	SCI journal-C
1980	2		
1981	1		
1982	2		
1983	1		
1987	1		
1988	5		
1990	1		
1991	2		
1992	4		
1993	4		
1994	6	2	
1995	7	1	
1996	14	4	
1997	12	4	
1998	22	6	
1999	28	8	
2000	22	8	
2001	33	5	
2002	27	7	
2003	49	14	3
2004	40	14	1
2005	57	17	0
2006	51	21	3
2007	70	23	3
2008	75	11	2
2009	84	16	3
2010	85	13	2
2011	87	13	4
2012	74	19	3
2013	107	18	6
2014	106	24	6
2015	145	18	5
2016	121	23	6
2017	138	28	7