A Functional Land Use Classification for Ecological, Production and Living Spaces in the Taihang Mountains

GENG Shoubao1,2, ZHU Wanrui1,2, SHI Peili1,3,*

1. Key Laboratory of Ecosystem Network Observation and Modeling, Institute of Geographic Sciences and Natural Resources Research, Chinese Academy Sciences, Beijing 100101, China;
2. University of Chinese Academy of Sciences, Beijing 100049, China;
3. College of Resources and Environment, University of Chinese Academy of Sciences, Beijing 100190, China

Abstract: A combination of rapid industrialization, economic development and urbanization has caused a series of issues such as resource shortages, ecosystem destruction, environmental pollution and tension between human needs and land conservation. In order to promote balanced development of human, resources, ecosystems, the environment, and the economy and society, it is vital to conceptualize ecological spaces, production spaces and living spaces. Previous studies of ecological-production-living spaces focused mainly on urban and rural areas; few studies have examined mountainous areas. The Taihang Mountains, a key area between the North China Plain and Beijing-Tianjin-Hebei area providing ecological shelter and the safeguarding of crucial water sources, suffer from increasing problems of fragile environment, inappropriate land use and tensions in the human-land relationship. However, studies of the ecological, production, and living spaces in the Taihang Mountains are still lacking. Therefore, this study, based on the concept of ecological-production-living spaces and using data from multiple sources, took the Taihang Mountains as the study area to build a functional land classification system for ecological-production-living spaces. After the classification system was in place, spatial distribution maps for ecological, production and living spaces were delineated. This space mapping not only characterized the present land use situation, but also established a foundation for future land use optimization. Results showed that the area of ecological space was 78,440 km², production space 51,861 km² and living space 6,646 km², accounting for 57.28%, 37.87% and 4.85% of the total area, respectively. Ecological space takes up the most area and is composed mainly of forests and grasslands. Additionally, most of the ecological space is located in higher elevation mountainous areas, and plays an important role in regulating and maintaining ecological security. Production space, mostly farmlands sustaining livelihoods inside and outside the region, is largely situated in lower elevation plains and hilly areas, as well as in low-lying mountainous basins. Living space has the smallest area and is concentrated mainly in regions with relatively flat terrain and convenient transportation for human settlements.

Key words: ecological-production-living space; land classification system; land function; spatial pattern; the Taihang Mountains

1 Introduction

China, the country with the world’s largest population, has a relatively low reserve per capita of resources. With rapid industrialization and booming economic development, especially after the reforms and opening-up of China, the demands for resources have grown steadily greater, thereby causing a series of problems. Serious problems that must be addressed include the contradiction between the needs of...
economic development and the shortage of land resources, the conflict between regional development and the need for ecological conservation, the chaotic exploitation of resources, and environmental pollution (Chen and Lei, 2015; Fu et al., 1999; Liu et al., 2014; Tan and Lyu, 2005). In addition, pressure from urbanization and social transformation in recent years has expanded the area of urban and rural construction lands, squeezing the space available for crop-lands, grasslands and forests, and threatening the farmland redline and ecological redline (Bai et al., 2014). The solution to these problems and challenges is dependent on a reasonable delineation of the geological spaces for human living, food production and the natural environment, and the scientific optimization of land use (Fan, 2007).

In order to promote the harmonious development of human wellbeing, natural resources, the ecological environment, and the economy and society, the 18th National Congress of the Communist Party of China proposed that “we should ensure that the space for production is used intensively and efficiently, that the living space is livable and proper in size, and that the ecological space is unspoiled and beautiful.” This requirement calls for the functional zoning of ecological-production-living (EPL) spaces and brings into focus the spatial patterns for the development of EPL spaces. Land is a limited resource and there is intense competition for the use of land for EPL purposes. Before the 21st century, the exploitation of land and resources was aimed mainly at furthering economic development. As a result, large areas of ecological function zones and eco-sensitive regions were disrupted or encroached upon, frequently leading to ecosystem degradation and other disasters (Chen and Shi, 2005; Huang and Fang, 2003; Zou and Shen, 2003). With ecological civilization construction now a part of the agenda of governments, decisions about the use of land resources have begun to take into consideration the ecological function of land, resulting in a transformation of focus from resource exploitation for production to EPL coordination. Consequently, there has been a perceptible improvement in the low level of ecological security. Moreover, the 19th National Congress of the Communist Party of China took a further step and proposed “speeding up reform of the system for developing an ecological civilization, and building a beautiful China”. Therefore, how to coordinate and optimize EPL spaces and thus realize regional sustainable development has become a focus of public concerns.

The functional classification and spatial delineation of EPL spaces form the basis for the optimization of land development space. Therefore, classification systems and methods for the quantitative spatial recognition of EPL spaces have been studied extensively. Fan (2015) drafted a proposal for the zoning of China that would divide territorial spaces at the national and provincial levels into four major functional types: urbanized zones, foodstuff-security zones, ecological safety zones, and cultural and natural heritage zones. Accordingly, major function zones on a countrywide scale should be designated to optimized, prioritized, restricted and prohibited zones. Fang (2013) compared national major function zones and EPL spaces, and constructed a systematic framework of China’s urban development patterns. Zhang et al. (2015) built an ecological-living-industrial land classification system on a country-wide scale based on land functions that incorporated the concept of ecological land. Liu et al. (2017) examined the spatial and temporal patterns of EPL spaces from a dynamic perspective. In addition, other researchers have comprehensively discussed the structure, function, identification, and optimization of EPL spaces in both urban and rural locales (Hu et al., 2016; Li and Fang, 2016; Tao et al., 2016; Wu et al., 2016; Xi et al., 2016; Zhu et al., 2015). In general, large-scale studies usually consider the issues at the national level, while small-scale studies prefer to select specific urban or rural regions as research targets. However, few studies target exploration of EPL space classifications for mountainous areas that have relatively large populations and are the most important areas for ecological functions. Mountains, which cover one fifth of the globe’s land area and two-thirds of China’s territorial land, are rich in natural resources and the origin points for many rivers. They provide both fresh water and ecological products for human beings. The rolling terrain and vertical heterogeneity of mountains tend to form diverse environments, making it possible for mountainous areas to be the best locations for biodiversity conservation (Chen, 2010). However, excessive exploitation and the disorderly management of mountain areas have caused various problems such as severe deforestation, land degradation and frequent disasters. Therefore, the classification of EPL spaces in mountainous areas is especially important. The characteristics of mountains determine that the ecological function is their major function. However, if a large population lives in a mountainous region, the area also has certain production and living functions. Hence, a scientific classification of ecological, production and living land spaces holds the key to resolving human-land tensions in mountainous areas.

The Taihang Mountains are an important ecological shelter for the Beijing-Tianjin-Hebei eco-sphere, safeguarding the ecological security of the economic circle around the capital of China and guaranteeing the water supply to the North China Plain. Previous studies have found that inappropriate land use in the Taihang Mountains has resulted in areas with sparse vegetation, serious soil erosion and a deteriorating environment, thereby threatening human survival and development (Ge et al., 2005; Tao et al., 2011). However, research into EPL spaces in this study area is still lacking. Therefore, this study took the Taihang Mountains as a case study, drawing on multiple sources to compile data on existing land use, natural reserves, eco-functional regions, rivers, soil quality and soil erosion in order to: (i) build a
functional land classification system for EPL spaces; and (ii) analyze the spatial patterns of EPL spaces. We expected that our research results would allow us to provide suggestions for coordinating ecological, production and living functions in the Taihang Mountains and maintaining sustainable development in mountainous areas.

2 Materials and methods

2.1 Study area description

The Taihang Mountains (34°55'–40°83'N, 110°21'–116°61'E, 3059 m a.s.l) is an important demarcation line in North China located in the transition zone between the second and third steps of China’s topography ladder. The mountain range is also the natural watershed between the Loess Plateau and the North China Plain, as well as a crucial safeguard of water sources and an ecological shelter for the North China Plain and the Beijing-Tianjin-Hebei urban agglomeration. The study area extends from Beijing City through Hebei Province and Shanxi Province to Henan Province, covering an area of ca. 1.369 × 10^5 km², accounting for 1.42% of China’s territory. It contains 101 counties that together have a relatively large population, amounting to 2.93% of the national population. There is constant human activity and environmental degradation is severe in much of the area. The study area possesses mountainous agroforestry ecosystems (Cao et al., 2018). The Taihang Mountains are typical earth-rocky mountains in North China that have unique climate conditions and a high degree of spatial heterogeneity. The mountains are also the central intersection zone of moisture gradients running from the east to the west of China and of heat gradients running from the south to the north of China (Cao et al., 2018). Annual average precipitation is about 550 mm with uneven seasonal distribution. Soil quality is poor with thin soil depth and high gravel content (Geng et al., 2018). These ecological disadvantages lead to various problems such as the incoordination of water and soil coupling, tensions in the human-land relationship and conflicts over allocations of land used for production, living and ecology (Liu et al., 2007).

2.2 Data sources

Land use data, soil erosion data and the spatial distribution data for first class rivers were provided by the Data Center for Resources and Environmental Sciences of the Chinese Academy of Science (http://www.resdc.cn). Data for natural reserves were obtained from World Database on Protected Areas (http://protectedplanet.net/). Eco-functional regionalization data were acquired from the Research Center for Eco-Environment Sciences of Chinese Academy of Sciences (http://www.ecosystem.csdb.cn/ecoass/ecoplanning.jsp). Soil quality data were derived from our previous work (Geng et al., 2018).

2.3 The land classification system of EPL spaces

Table 1 Ecological-production-living land classification system of the Taihang Mountains

<table>
<thead>
<tr>
<th>Class</th>
<th>Key ecological space</th>
<th>General ecological space</th>
<th>Ecological capacity space</th>
<th>Production space</th>
<th>Potential production space</th>
<th>Living space</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class I</td>
<td>natural reserve, eco-functional region, irrigation canal and ditch, lake, reservoir and pond, beach and flats, first class rivers and riparian buffers within 2 km</td>
<td>wood land (canopy density &gt; 30%), shrubbery land (canopy density &gt; 40%), high coverage grassland (coverage &gt; 50%), medium coverage grassland (20% &lt; coverage &lt; 50%)</td>
<td>sandy land, saline-alkali land, wet land, bare land, exposed rock and shingle land, low quality sparsely forested woodland (10% &lt; canopy density &lt; 30%), low quality low coverage grassland (5% &lt; coverage &lt; 20%)</td>
<td>irrigated paddy field, dry land, young afforestation land, slash, seedling nursery, garden plot</td>
<td>high quality sparsely forested woodland (10% &lt; canopy density &lt; 30%), high quality low coverage grassland (5% &lt; coverage &lt; 20%)</td>
<td>city and town areas</td>
</tr>
<tr>
<td>Class II</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>residential quarters in rural areas</td>
</tr>
<tr>
<td>Class III</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>industrial and mining land, land used for transportation</td>
</tr>
</tbody>
</table>

Based on principles of environmental protection, production security and living guarantee, this study comprehensively considered the priority requirement to protect ecologically sensitive areas, environmentally vulnerable regions and specially protected zone, whilst ensuring the existence of essential areas for human living and production. Based on the current classification system of Land Use and Cover Change in China (CNUUCC) (Liu, 1996) and the spatial distribution of natural reserves, eco-functional regions and water areas, as well as the conditions of soil quality and soil erosion, we integrated and re-classified the CNUUCC data based on the concept of EPL space, and then we mapped the spatial patterns of ecological space, production space and living space in the Taihang Mountains. This re-classification system consisted of three classes (Table 1). Class I was the EPL spaces including ecological space, production space and living space. Class II subdivided Class I on the basis of the importance of the land function, the stability of the environment and the localization of human settlement. Class III showed the specific land use types under the Class II classification system.

Ecological space is the area where natural configurations fulfill their major function of providing ecological products...
and ecosystem services (Huang et al., 2017). The Taihang Mountains have a unique geographical location and its ecological functions play a decisive role in ensuring the ecological security of the North China Plain and the Beijing-Tianjin-Hebei area. Based on the relative importance of the areas that regulate, sustain and guarantee ecological security, ecological space is divided into key ecological space, general ecological space and ecological capacity space (Table 1). Key ecological space is essential to maintain ecological security. For example, natural reserves are areas where important ecosystems, precious or endemic species, unique landscapes or landforms, and nature relics are located. Thus, natural reserves are considered key ecological spaces because of their role in protecting and managing typical ecosystems, endangered species of flora and fauna, and special relics in the Taihang Mountains. Eco-functional regions are places that provide vital functions such as water and soil conservation, flood regulation and biodiversity preservation. Due to the ecological sensitivity and importance of ecosystem services in the Taihang Mountains, eco-functional regions should also be included as key ecological space. In addition, the Taihang Mountains have limited water resources (Wang, 2016), so the river systems and water bodies were given careful consideration. General ecological space is defined as woodlands and grasslands that have obvious ecological functions that are of great significance to sustain regional eco-security. At high elevations in the Taihang Mountains, there are steep slopes that tend to have woodlands with high canopy density and grasslands with medium to high coverage. Croplands often give way to shrub lands or grasslands and there is little human activity. These areas mainly have ecological functions, so they are classified as general ecological space. Ecological capacity space generally refers to unused lands, including sandy land, saline-alkali land, wetland, bare land and exposed rock and shingle land. This kind of land takes up little area but includes severely degraded lands that have certain ecological values and cannot be disturbed arbitrarily (Zhang et al., 2015). In addition, some land with poor natural conditions and a high risk of land degradation should also be included as ecological capacity space. For instance, low quality sparse woodlands and low coverage grasslands usually have low soil quality and moderate to severe soil erosion.

Production space includes areas that provide industrial products, agricultural products and services (Huang et al., 2017). The Taihang Mountains account for 1.42% of the China territory, but have 2.93% of the country’s total population. Thus, there is a great demand for resources and this determines the importance of the area’s production function. Based on the present status of land use and the stability of the environment, production space is classified as actual production space or potential production space (Table 1). Actual production space refers to land with obvious production functions covered by the existing land use classification system. For instance, croplands in the Taihang Mountains are mainly distributed in the lowlands of hilly zones or on gentle hillsides that are terraced. The croplands are the most important production space. Moreover, some forested lands such as garden plots and seedling nurseries can supply products other than grain, so these lands also constitute an important part of actual production space. Potential production space is land which has good prospects for development despite currently having low production ability. Included in this category are high quality sparse woodlands and low coverage grasslands. This type of land has weak ecological functions but high soil quality and, therefore, is the kind of land that can easily be exploited with a low risk of soil erosion. If such lands were to be transformed into garden plots, timber forests or pasture lands, productivity would be improved and the environment would be more stable.

Living space consists of areas that are the major function of which is human settlement (Huang et al., 2017). Based on geographical locations, living space in the Taihang Mountains was divided into urban living spaces, rural living spaces and other living spaces (Table 1). Specifically, urban living space refers to large, medium-sized and small cities as well as built-up areas at and above the township administrative level. Rural living space is the residential areas of individual villages. Other living space refers mainly to construction lands such as industrial and mining lands, and land used for transportation. Construction lands are a necessary part of daily life even though they possess certain production functions, so they are classified as other living space in this study.

2.4 Spatial identification of EPL spaces

On the basis of the land classification system described in Section 2.3 and with reference to soil quality and soil erosion, we took existing land use types, the ranges of natural reserves, eco-functional regions and water areas into account, and integrated the CNLUCC into EPL space mapping. Then we used the ArcGIS 10.2 platform to complete a spatial visualization of EPL spaces. The current classification system of CNLUCC consists of six primary categories and twenty-five subcategories (Liu, 1996). The land use types in the Taihang Mountains include cultivated lands, forest lands, pasture lands, water areas, construction lands and unused lands. The detailed scheme for the spatial identification of EPL spaces is described below.

2.4.1 Identification of ecological space

The identification of key ecological space focused on the distribution of natural reserves, eco-functional regions and water areas. Areas providing important ecosystem services such as water and soil conservation, flood regulation and biodiversity preservation were, with the exception of cultivated lands, construction lands and residential lands in these areas, extracted as key ecological space. In addition, riparian
buffers within 2 kilometers of first class rivers were extracted as key areas for riverbank protection.

General ecological space was identified as the areas defined by the current land use classification system as woodlands, shrublands and medium to high coverage grasslands. Areas designated key ecological space were excluded.

Lands defined as unused by the current land use classification system were regarded as ecological capacity space. In addition, low quality, sparsely forested woodlands and low coverage grasslands with soil quality lower than 0.5 (Geng et al., 2018) and moderate or relatively severe soil erosion were also designated ecological capacity space.

2.4.2 Identification of production space

Areas of the current map defined as ecological space were excluded from consideration, and then cultivated lands and other woodlands including young afforestation lands, slash-ies, seedling nurseries and garden plots were extracted as actual production space, while high quality sparsely forested woodlands and low coverage grasslands with soil quality greater than 0.5 (Geng et al., 2018) and slight or no soil erosion were extracted as potential production space.

2.4.3 Identification of living space

Given the correspondence of the EPL classification system and the CNLUC classification system, areas of cities and towns, rural areas and construction lands were extracted as urban living space, rural living space and other living space.

3 Results

3.1 Spatial patterns of the ecological space

Ecological space in the Taihang Mountains is divided into three categories, key ecological space, general ecological space and ecological capacity space (Fig. 1). Ecological space is widely distributed in areas with an average elevation higher than 1000 m and the average slope of approximately 15 degrees, except eco-functional regions. Different categories of ecological space have obvious spatial differences. Key ecological space is located mainly in the eastern part of the study area, and of this ecological space, eco-functional regions are concentrated at elevations below 1000 m. This region is the transition zone from mountainous areas to the North China Plain, and provides important soil and water conservation ecosystem services. Natural reserves and water bodies that have the functions of protecting the important water sources, wet lands, landscapes and endangered species are scattered at elevations between 750 m to 1700 m. General ecological space takes up the largest area, accounting for 53.97% of the total ecological space. Wood lands and high coverage grasslands are located mainly in the south and north of the study area at elevations ranging from 700 m to 1700 m; high coverage grasslands are found primarily near the summits of the Taihang Mountains towards the north of the study area. Shrublands and medium coverage grasslands spread throughout the middle part of the study area and are scattered in the north and south. Shrublands are principally distributed below the elevation of 1500 m. The average slope of wood land and shrubland areas is about 16 degrees, greater than the 13 degrees common for grasslands. Ecological capacity space is scattered sparsely throughout the study area and takes up smallest area, accounting for only 11.16% of the ecological space.

3.2 Spatial patterns of the production space

Production space in the Taihang Mountains is composed of actual production space and potential production space (Fig. 2). Actual production space includes irrigated paddy fields, dry lands and some forested lands like garden plots. Among these lands, dry lands take up the largest area and account for 98.41% of the total actual production space, while the...
percentages for irrigated paddy fields and woodlands are only 0.61% and 0.97%, respectively. Cultivated lands are the most important production space, among which approximately 80% of the dry lands are distributed below the elevation of 1000 m and have slopes of less than 5 degrees. Irrigated paddy fields are generally concentrated near water areas. Potential production space has average elevations higher than 1000 m and higher slopes greater than 10 degrees. High quality, low coverage grasslands account for 42.35% of the potential production space, and are spread from the mid-western to the northern part of the study area, while high quality, sparsely forested woodlands are mostly distributed in the south and northeast. In addition, compared with the spatial distribution map for organic matter in soil, actual production space covers areas with relatively high organic matter content.

3.3 Spatial patterns of the living space

Compared to the areas of ecological space and production space, the area of living space is much smaller. Most living space is dispersed and in rural areas, while urban areas are usually distributed as concentrated patches and construction lands are commonly situated around cities and towns (Fig. 3). Living space is found at lower elevations and has less slope than ecological space and production space. Elevations trend upward from urban to rural and construction lands. Specifically, the average elevations of urban areas, rural areas and construction lands are 362 m, 452 m and 509 m, respectively, and the slope in 80% of these three living space areas is 1.5 degrees, 2.7 degrees and 5.5 degrees, respectively.

3.4 Spatial patterns of the EPL spaces

The spatial distribution of EPL spaces in the Taihang Mountain is largely influenced by terrain types and landforms. The ecological space dominated by woodlands and grasslands is centered mainly in mountainous areas with high elevations, including around Zhongtiao Mountain, Wangwu Mountain, Taiyue Mountain, Yuntai Mountain and Linlv Mountain in the south and Xizhou Mountain, Wutai Mountain, Heng Mountain and Xiaovutai Mountain in the north of the Taihang Mountains (Fig. 4). These mountainous areas have little human activity and thus ecological functions are vital. Unlike ecological space, production space dominated by cultivated lands is widely distributed in plains and hilly zones surrounding the mountains, such as the Taihang piedmont plain in the east of the Taihang Mountains, and in relatively low elevation basins within the mountainous regions, such as Yuncheng basin, Linfen basin, Changzhi basin and Linzhou basin in the south, Taiyuan basin in the middle, and Xinding basin and Datong basin in the north (Fig. 4). Human activities in these areas are commonly intensive, thereby providing convenience for production functions. Living space is often surrounded by production space and is located principally in the Taihang piedmont plain and flat land basins with convenient transportation (Fig. 4). The analysis of EPL spaces with elevation and slope indicates that EPL spaces in the Taihang Mountains show obvious vertical differentiation. Specifically, ecological space is primarily distributed at regions with higher elevations (700–1700 m) and has an average elevation of 1100 m and an average slope of 15 degrees. Lower elevations are observed to have the distribution of production space, which is mainly located in areas with elevations below 1000 m and slopes of less than 7 degrees. Living space tends to situated in relatively flat regions with elevations below 700 m and slopes of less
than 4 degrees.

Area statistics indicate that the areas for ecological space, production space and living space are 78.44 thousand km², 51.86 thousand km² and 6.65 thousand km², respectively, accounting for 57.28%, 37.87% and 4.85% of the total area, respectively (Table 2). Ecological space is dominant in the study area, followed by production space and living space. The Class II designation of actual production space from the classification system shown in Table 2 has the largest area, accounting for 36.12% of the total area in the study area. It is followed by general ecological space (30.91%) and key ecological space (19.98%). Other Class II categories occupy much smaller areas with their total proportion coming to no more than 7%. The Class II designation of other living space has the smallest area, only accounting for 0.73% of the total area.

4 Discussion

An accurate classification of EPL spaces not only describes the current situation with respect to land use, but also serves as a basis for making decisions about the development and optimization of national land space in the future. First, the classification of EPL spaces identifies the major functions of land, and the spatial identification of EPL spaces defines the scope for each kind of space. This is of great significance for land planning and exploitation as well as for resolving human-land conflicts (Liu et al., 2017, Ma et al., 2014). This is especially the case for mountainous regions. The ecological shelter effect that mountains provide plays a decisive role in the ecological security of the nation. Thus, any form of damage to or encroachment on ecological space, especially key ecological space, is not permitted. At the same time, the identification of EPL spaces is a prerequisite for the optimal allocation of land resources, and the quantity ratios and the spatial distribution of the structure of EPL functions are crucial to land use optimization (Huang et al., 2017, Ma et al., 2015). Different regions have varied environmental carrying capacities for resources and distinctive developmental orientations. With need to promote national ecological civilization as a backdrop, the sustainable use of land can only be accomplished by prioritizing the protection of the ecological functions of mountains and, simultaneously, coupling environmental needs with EPL functions.

In this study, we investigated the land classification system and spatial distribution of EPL spaces in the Taihang Mountains. Our results indicate that the study area is dominated by ecological space, which accounts for more than half of total area. We took eco-functional regions, ecologically sensitive areas and environmentally vulnerable zones into account to define ecological space, in order that the ecological space is able to protect the ecological redline and guarantee the major functions of mountains to regulate and sustain the environment and ecological security. In addition, long-term development in the Taihang Mountains has resulted in production space, which accounts for 37.87% of the total area, competing with ecological space; the study area offers adequate guarantees for prime farmland. Our findings with respect to EPL functions of the Taihang Mountains are consistent with prior work on national land function classification. For example, a body of work defining major function oriented zones in China suggests that the Taihang Mountains are one of the areas where protection and development need to be carefully balanced, so land use plans in the future should make appropriate reductions to the area of farmlands and increase forest coverage (Fan, 2015). Moreover, considering the environmental vulnerability and the important linkages of the area to the North China Plain, urban and rural planning is required to coordinate the utilization of land and the restoration of degraded ecosystems in the future. Our findings are consistent with previous EPL space studies (Liu et al., 2017, Zhang et al., 2015) which demonstrated that the Taihang Mountains were situated at the transition zone from the vast ecological space in the west to the production and living space in the east of China. In this study area, Ecological space distributes alternately with production space from the west to east (Fig. 1 and 2). Furthermore, the ecological space patches at the junction of ecological space and production space are fragmental due to the complexity of the topography and the vertical zone configuration.

The Taihang Mountains are of vital strategic importance to maintaining the ecological balance in North China. The

<table>
<thead>
<tr>
<th>Class I</th>
<th>Area (thousand km²)</th>
<th>% of the total area</th>
<th>Class II</th>
<th>Area (thousand km²)</th>
<th>% of the total area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ecological space</td>
<td>78.44</td>
<td>57.28</td>
<td>Key ecological space</td>
<td>27.36</td>
<td>19.98</td>
</tr>
<tr>
<td>Production space</td>
<td>51.86</td>
<td>37.87</td>
<td>General ecological space</td>
<td>42.33</td>
<td>30.91</td>
</tr>
<tr>
<td>Living space</td>
<td>6.65</td>
<td>4.85</td>
<td>Ecological capacity space</td>
<td>8.75</td>
<td>6.39</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Actual production space</td>
<td>49.47</td>
<td>36.12</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>Potential production space</td>
<td>2.39</td>
<td>1.75</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>Urban living space</td>
<td>1.54</td>
<td>1.12</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>Rural living space</td>
<td>4.11</td>
<td>3.00</td>
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<td></td>
<td></td>
<td></td>
<td>Other living space</td>
<td>1.00</td>
<td>0.73</td>
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</table>
key ecological space is distributed mainly between the mountain peaks and the piedmont in the east of the study area. Most of the key ecological space is located in a typical environmentally vulnerable zone in Hebei Province (the eastern part of the study area) with high elevations and slope variations, sparse vegetation, and severe soil erosion. Previous studies showed that the ecological security of the Taihang Mountains in Hebei was generally low and in an early to medium warning state (Liu et al., 2009). Because environmental quality was poor, the environment was prone to degradation that would be difficult to recover from (Liu et al., 2009). Moreover, due to the impact of terrain features and precipitation, the sensitivity of the area to soil erosion and land degradation is high and the Hebei Taihang Mountains are an area with high environmental sensitivity (Yang et al., 2016). In addition, because of the important ecosystem services for preserving biodiversity and conserving soil and water, the Hebei Taihang Mountains have been designated a provincial-level key eco-functional region in the ecological function classification for Hebei Province (Yang et al., 2016). The classifications of EPL spaces in our study are similar to the vulnerable eco-security zones and environmental sensitive areas, as well as the key eco-functional regions as depicted above, indicating our results are reasonable and reliable.

Environmental change is the external manifestation of the weakening or enhancing of ecosystem services. The environment is sustaining stability and health only if the classification of EPL spaces shows a fulfillment of ecosystem services. The biophysical factors of the Taihang Mountains are clearly differentiated vertically. Based on ecosystem services differentiation and elevation, Gao et al. (2018) divided the Taihang Mountains into three ecological zones: the highland zone, the mid-mountain zone and the hilly zone, and analyzed their respective ecosystem service values. The study found that the main ecosystem functions in the highland zone were regulation, support and the provision of cultural services, and provisioning services in the hilly zone, while these four ecosystem services were all equally important in the mid-mountains. The results of our study of EPL spaces strongly support the existence of vertical variations of ecosystem services. The average elevations of ecological space, production space and living space in the study are approximately 1100 m, 750 m and 440 m, respectively. With the decrease of elevation, ecosystems shift from natural secondary forests to ecological plantations, and then from plantations to agroforestry systems. Simultaneously, the corresponding ecosystem services change from climate regulation and water production to control of soil erosion and water conservation, and then to the provisioning of raw materials and food. Water and soil conservation are two of the most important services in mountainous areas. Nevertheless, evidence from previous studies has revealed that there is a serious water and soil loss problem in the Taihang Mountains, and the soil and water loss sensitivity in the Taihang Mountains area of Hebei Province has a sensitivity grade from moderate to high (Wang et al., 2014). Moreover, water and soil conservation zones normally have formed in these sensitive regions (Wang, 2011). In addition, the ecological vulnerability of soil and water conservation in the hilly zones of the northwestern and southwestern parts of the Taihang Mountains has been reported to be extreme or very extreme (Zhao, 2014). Our results of ecological space classification are in line with these earlier findings. For instance, key ecological space is mainly distributed in the east of the Taihang Mountains to provide protection for the most affected areas suffering from water and soil loss in Hebei Province. Woodlands and grasslands that dominate the general ecological space in the west help to improve water and soil conservation and maintain regional ecological security. Scientific research is usually designed to solve practical problems. Considering the importance of water conservation capacity and the existence of problems with this in the Taihang Mountains, a large number of studies have been done to evaluate water carrying capacities of forests, mainly in the eastern counties of Xingtai, Pingshan, Fuping, Mancheng, Yi and Laishui in western Hebei Province, and Lingchuan, Changzhi, Huguan, Lucheng and Licheng in southeastern Shanxi Province, as well as Jiyuan and Huixian in northern Henan Province and areas around Beijing City (Ma et al., 2017). Our results also highlight that these eco-functional regions are being protected and define most of the eastern Taihang Mountains as key ecological space (Fig. 1).

The exploitation of land resources should be undertaken in accordance with land properties, so the classification of EPL spaces should correspond to land suitability. Evaluations of land suitability in the Hebei Taihang Mountains have revealed that land suitability for cultivation tends to increase as one moves from mountainous areas in the west to piedmont plains in the east of Hebei Province, whereas land suitability for forestry showed the opposite trend (Bai, 2012; Yu, 2004; Zheng, 2015). Furthermore, the analysis of agricultural production potential indicated that the average yield of maize and wheat and the production potential provided by light, temperature, water and soil increased gradually from mid-mountain zones to hilly zones and then to piedmont plains (Li, 2012). Our classification of EPL spaces reflects the spatial patterns of land suitability. The elevation and slope decreases step by step as one goes from ecological space to production space to living space. Ecological space is located mostly at higher elevations and has steeper slopes, while production space is often found in hilly regions, mountainous basins and piedmont plains at lower elevations and with less slope. However, land suitability analysis indicates that some of the existing croplands are located on land with low suitability for crop production, so it is essential to implement policies that move farming away from these unsuitable croplands.
In this study we build a land classification system for EPL spaces in the Taihang Mountains, but there are still many shortcomings to this research; further improvements are needed to support our results. First, our EPL space classification system is simply a qualitative collecting, combining and reclassifying of existing land classification systems. It does not include a quantitative measure of land functions. A comprehensive and refined quantitative land classification incorporating landscape values (de Groot, 2006), ecosystem services (Jin, 2014) and land suitability (Wu et al., 2016) that makes the EPL space classification more precise and practical is required for further study. Next, our land classification system does not consider the multi-functionality of land. Land can have a single dominant function or combine major and minor functions. For example, the primary function of farmland is production, but cultivated land also has certain ecological functions. Accordingly, determining what, if any, semi- or sub-functions land has can make land classifications more accurate (Liu et al., 2017). In addition, in a situation where population is out-migrating from the Taihang Mountains, further investigation is needed to reveal the dynamics and mechanisms of EPL spaces.

5 Conclusions

In this study, we delineated the spatial patterns of EPL spaces in the Taihang Mountains based on a preliminary land classification system. Results demonstrated that ecological space is dominant in the study area, followed by production space and living space. The spatial distribution of EPL spaces varied dramatically with topography. Ecological space, dominated by woodlands and grasslands, is largely located in the mountainous areas with high elevations and steeper slopes. Production space is mainly composed of farmlands and is widely distributed in basins and piedmont plains with lower elevations and gentler slopes. Living space generally refers to construction land at the lowest elevations and with the least slope. Our classification of ecological, production and living spaces is broadly consistent with what previous studies have found with respect to the major function oriented zonation of land, ecologically vulnerable and sensitive zones, the vertical differentiation of ecosystem services, and land suitability. This supports our results indicating that EPL spaces can simultaneously and effectively protect the environment and guarantee production and living.

References

Liu X, Ge J F, Feng X H. 2007. Study on ecological security of land re-