

Effects of land-use intensity on ecosystem services and human well-being: a case study in Huailai County, China

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Abstract The present study aimed to investigate the effects of land-use intensity (LUI) on ecosystem services and human well-being in a rural county of China. LUI was assessed using the landscape development intensity index, key ecosystem services (crop production, soil conservation and climate regulation) and human well-being (standard of living and food security), which were quantified by proxy indicators. In addition, correlation method and ANOVA were used to reveal the effect of LUI on ecosystem services and human well-being. These results showed that LUI was correlated with changes in ecosystem services and human well-being in the study area. As LUI increased, there were increases in crop production and living standard well-being and a reduction in regulating services (soil conservation and climate regulation). The statistical results between LUI and food security were not significant. Furthermore, there were tradeoffs between provisioning and regulating services and synergies between regulating services when the LUI increased. These findings revealed the different responses of ecosystem services and human well-being to increasing LUI and provided guidelines for land-use decision-making and ecosystem services management.

Keywords Land-use intensity · Crop production · Regulating services · Human well-being · Index · Mountainous county

Introduction

The Millennium Ecosystem Assessment (MA) proposed two important concepts, ecosystem services and human well-being, and a new conceptual framework to quantify the interactions between human and environment. Ecosystem services are defined as the functions of ecosystems that have value for human welfare (Pinto et al. 2014). They include four components: provisioning services, regulating services, cultural services and supporting services (Millennium Ecosystem Assessment 2003). Human well-being can be defined as human experiences, including the basic materials for human lives, freedom of choice, health, good social relations, a sense of ‘cultural identity’ and security (Pinto et al. 2014). Human well-being is dependent on the continuous flow of ecosystem services. Ecosystem services and human well-being have been increasingly applied to investigate environmental conservation, poverty alleviation and sustainable development in many researches (Raudsepp-Hearne et al. 2010b; Rodriguez-Loinaz et al. 2015; Swallow et al. 2009). The conceptual framework connects drivers of change, ecosystem services and human well-being. Human activity on ecosystems is the major driver to change well-being and ecosystem services.

In recent years, studies of the effect of human activity, particularly the intensity of human activity, on ecosystems have received a fair amount of attention. Several studies have shown that the intensity of human activity is strongly related to the ecological processes of natural communities

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(Margritter et al. 2014; Simons et al. 2015; Valtanen et al. 2014). In these studies, human activity intensity is commonly expressed as land-use intensity (LUI). For example, Margritter et al. (2014) studied the effect of land-use development intensity on the soil and water quality of wetland, and their results showed that with increased LUI, soil nutrients decreased and the nutrients in surface water increased. Valtanen et al. (2014) found that the generation of storm water was positively correlated with LUI. Moreover, in the studies that investigate the effect of human activity intensity on ecosystem services, they often focus on narrow selections of ecosystem services and can not reveal the variation and interaction between different ecosystem services with increasing human activity intensity. The responses of human well-being to increasing human activity are also still ambiguous.

The pressure from land-use has intensified over the last 40 years in Asia due to the population growth in regions with fertile land (Spiertz 2013). Since the economic reforms in China, Chinese rural areas have experienced great changes of land-use and rapid economic development. In the development of rural regions which are located in mountainous areas, administrators often focus on economic benefits and neglect the conservation of natural ecosystems. It is necessary to study the effect of LUI on ecosystem services and human well-being in Chinese rural areas to understand how LUI could limit the sustainable development of China.

Studies evaluating the ecosystem services and human well-being at the local scale, particularly the rural watershed, have been performed around the world (Pacheco et al. 2014; Pereira et al. 2005; Swallow et al. 2009). The watershed is a landscape unit, and its ecosystem spatial patterns and ecological processes have their own unique features. The rural communities residing in a watershed are often the most directly linked to ecosystems, because they frequently depend on local ecosystem services and are most directly affected by ecosystem degradation (Millennium Ecosystem Assessment 2003). The mountainous regions of China cover 70 % of China's land area and are home to 64 % of China's rural population. However, the efforts to integrate ecosystem services and human well-being have so far remained elusive in these regions. This study focused on Huailai, a rural county located in a watershed in a mountainous region and a typical representative of the kind of mountain-basin system of north China which is sensitive to global change (Xu and Tang 2015). This region has various ecosystems, such as forested hills, preserved woodlands, prime agricultural lands and water reservoirs. This region is also host to a great proportion of agricultural population (70.10 % of total population is agricultural population) who are dependent on ecosystems for their livelihood (Huailai

Statistic Bureau 2010). Moreover, Huailai borders with the Chinese capital of Beijing. The development of counties bordering Beijing is part of the integration of the Beijing–Tianjin–Hebei region (Feng 2014). Therefore, understanding the relationship between LUI and ecosystem services and human well-being is not only critical for the improvement of environment and livelihood of the study area, but also important for the integration development of the Beijing–Tianjin–Hebei region.

This study is an empirical study in a Chinese mountainous county based on the conceptual framework proposed by MA. The primary objective of our study was to assess the effect of LUI on ecosystem services and human well-being. The specific objectives include: (1) assessing the LUI scores of each town and the landscape metrics (LMs) of different LUI regions; (2) quantifying the ecosystem services and human well-being; and (3) illustrating the variations of ecosystem services and human well-being at different levels of LUI.

Materials and methods

Study area

Huailai lies in the southeast of the farming pastoral zone of northern China (115°16'–115°58'E, 40°04'–40°35'N); and covers an area of approximately 1801 km² (Fig. 1). It is dominated by temperate semi-arid continental monsoonal climate. The mean annual temperature is 9.2 °C. The average annual precipitation is 383 mm, and 70 % of the rainfall occurs during June to August. Farmlands of study area are located in flat lowlands, and pastures, vineyards and orchards are located in gentle slopes of the valley, with small forest spots in the adjacent hillsides and continuous forests in the highlands. There are 17 towns in the study area, and they are different in land-use compositions and economic development levels.

Huailai is one of the key counties of the soil and water conservation project in China and is involved in the Three North Shelterbelt Program (Yang et al. 2004). These environmental protection projects, particularly the planting and protection of shelter forest, are helpful for improving the ecological functions (such as soil and water conservation, wind sheltering and sand fixation, climate regulation and pollution abatement) and human well-being in the study area. In recent years, resources development and economic growth of this region have brought about some environmental degradation, such as grassland degeneration, soil erosion and water eutrophication. Thus, local administrators are faced with tradeoffs between economic development and environmental conservation (Lou 2003; Luo et al. 2013; Yang et al. 2004).

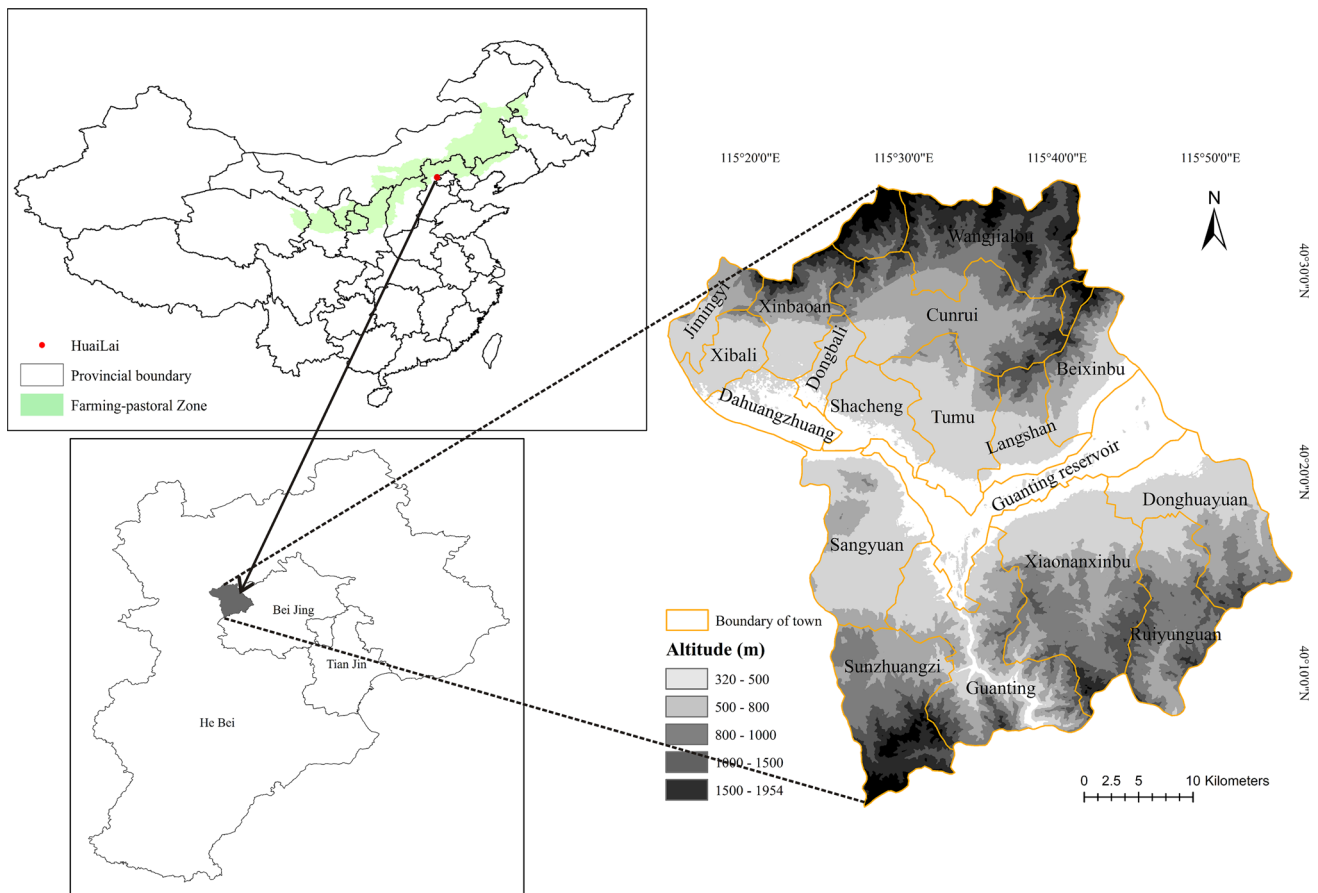


Fig. 1 Geographic location and digital elevation model of Huailai mountain-basin

Land-use intensity and landscape metrics assessment

In this paper, LUI is defined as the intensity of the impacts from human dominated activities which are experienced by land ecosystems. The formula for calculating LUI used in this paper is proposed by Brown and Vivas (2005). This formula is based on the area of different land-use classes and the energy and material use per unit area of land-use (Brown and Vivas 2005). It has been confirmed as an effective indicator that can evaluate the cumulative effects of humans along a continuous gradient (Cohen et al. 2004; Mack 2006; Margritter et al. 2014). The LUI value of each town was calculated as the area weighted for each land-use class using Eq. (1):

$$LUI = \sum \%LU_i \times LDI_i \tag{1}$$

where $\%LUI_i$ is the percent of land-use i of every town and LDI_i is the LDI coefficient for land-use category i . The LDI coefficients are normalized energy values (range from 1.0 to 10.0). In this formula, the emergy is a metric for quantify human activity. It is a measure of energy and material

(electricity, fuels, fertilizers, pesticides and water) used directly and indirectly to make a product or service (Odum 1995). A higher coefficient indicates that the degree of human disturbance is greater.

The land-use data of 2010 used in this paper were obtained from supervised classification of Landsat5 TM image on August 15, 2010 (path 32 and row 124). The ground control points and land-use map in 1990 were used to rectify the interpretation result. Land-use in Huailai consisted of construction land, cultivated land, grassland, forest, water body and bare land. To accurately evaluate the LUI of the study area, we calibrated the LDI coefficient for every land-use type (Table 1) based on the emergy weight coefficient proposed by Brown (Brown and Vivas 2005; Mack 2006; Margritter et al. 2014). The results of the LUI reflect the intensity of human use landscape, and a larger value corresponds to a higher LUI.

With regard to the landscape spatial pattern of different LUI regions, this paper focused on LMs which are applicable at landscape-level and comparable between different landscapes. Patch area (AREA), largest patch index (LPI) and edge density (ED) are indexes about the size and edges

Table 1 LDI coefficient for land-use category

Land-use categories	Construction land	Cultivated land	Grassland	Forest	Water body	Bare land
LDI coefficient	8.43	7.00	3.41	1.00	1.00	1.00

of patches at landscape level, they are better predictors of habitat quality (Lee et al. 2015). Shape index (SHAPE) measures the complexity of patch shape compared to a standard shape of the same size. Edge contrast index (ECON) measures the magnitude of difference between adjacent patch types with respect to ecological attributes, and it can effectively reflect the difference and pressure in edges (Frank et al. 2012). Effective mesh size (MESH) is a sensitive index to address landscape fragmentation. The calculation of these LMs was conducted in FRAGSTATS 4.1 software.

Quantification of ecosystem services and human well-being

The key ecosystem services of the study area were identified, including provisioning services (crop production) and regulating services (soil conservation and climate regulation). These ecosystem services were calculated for each town in Huailai. The provisioning service (crop production) of every town was derived from statistical data (Huailai Statistic Bureau 2010). The soil

conservation ecosystem service of each town was defined as the mean of the soil conservation calculation values calculated for each town. The calculation of soil conservation mainly referred to the formula proposed by Zhang et al. (2004), using precipitation, soil, digital elevation model (DEM) and normalized difference vegetation index (NDVI) data with 250 m resolution and a unified geographic coordinate system. The climate regulation ecosystem service of each town was defined as the mean of a proxy indicator in the vegetation-cover region of each town. The climate regulation ecosystem service was predicted by the NDVI data with 250 m resolution. The spatial statistics of soil conservation and climate regulation were conducted in ESRI ArcGIS 10.0. Additional information about the indices of these key ecosystem services can be found in Table 2.

In this study, we quantified two measures of human well-being for every town, they are living standards and food security. They are both components of the human survival needs described in Maslow's hierarchy of need (Maslow 1943). The two measures of human well-being of each town were both derived from statistical data (Huailai

Table 2 Ecosystem services and human well-being proxy indicators used in this study

	Description	Mean and range for 2010	Data sources
Ecosystem service			
Crop production	Yield per hectare of the main agricultural crops in Huailai, including corn, sunflower, grapes, crab apple and apricot	5,102.49 kg/ha (1,355.89–10,128.99)	Huailai Statistics Yearbook of Social and Economic (Huailai Statistic Bureau 2010)
Soil conservation	Soil retention is the reduced erosion caused by current land use/land cover patterns and soil erosion control practices	79,562 kg/ha (0–4,588,000)	Monthly precipitation data in 2010 (China Meteorological Data Sharing Service System); soil erodibility (Men et al. 2004) and map of soil types (Soil Survey Office of Hebei Province); Digital elevation model (DEM) (Geospatial Data Cloud Website); MODIS-NDVI dataset from April to October 2010 (USGS)
Climate regulation	Normalized difference vegetation index (NDVI) during the growing season	0.55 Unitless (0–0.82)	USGS
Human well-being			
Living standards	The net income of rural households per capita of every town	7,648.18 Yuan/person (4,423–9,990)	Huailai Statistics Yearbook of Social and Economic (Huailai Statistic Bureau 2010)
Food security	Reduction of crop production per hectare on cultivated land caused by natural disaster of each town	508.47 kg/ha (0–1,484.69)	Huailai Statistics Yearbook of Social and Economic (Huailai Statistic Bureau 2010)

Statistic Bureau 2010). Additional detailed information can also be found in Table 2.

For comparative purposes, the ecosystem services were standardized using Eq. (2), and the overall regulating service was calculated as the mean of soil conservation and climate regulation rescaled values. In this equation, I_{norm} is the standardized index value of the ecosystem service, the score of which is between 0 and 1, where higher scores indicated a better condition; I is the value of a specific ecosystem service; and I_{min} and I_{max} correspond to the minimum and maximum values of the specific ecosystem service of different LUI.

$$I_{norm} = \left(\frac{I - I_{min}}{I_{max} - I_{min}} \right) \quad (2)$$

Statistical analysis

ANOVA and Spearman correlation analysis were performed in this study; with a significance level of 0.05. ANOVA revealed a significant difference of ecosystem services and human well-being between different LUI levels. LUI, ecosystem services and human well-being were non-normally distributed, as confirmed using the Kolmogorov–Smirnov test. Thus, Spearman correlation coefficient analysis, a nonparametric measure of statistical dependence between variables, was performed to establish the strength of the relationship between variables. These statistical analysis methods were performed using SPSS20.0.

Results

Assessment results of land-use intensity

The LUI score of seventeen towns in Huailai ranged from 2.13 to 6.37; these towns were classified into three LUI levels. Towns with LUI score ranging from 2.13 to 3.54 were referred to as low LUI; values ranging from 3.54 to 4.95 were referred to as intermediate LUI; LUI scores ranging from 4.95 to 6.37 were referred to as high LUI (Fig. 2). There was a clear difference in the land-use structure between the three LUI levels. Low LUI regions had a low percentage of construction and cultivated land. However, their proportions of forest and grassland were relatively high. Towns belonging to low LUI aggregated in the southern and northern mountainous areas of the study area as shown in Fig. 2. With regard to the intermediate LUI, the proportions of construction and cultivated land were relatively higher, and

the percentage of forest and grassland were relatively lower. High LUI towns had the highest proportion of construction and cultivated land and the lower proportion of forest. Towns belonging to high LUI were located in the flat region close to the reservoir in the study area.

The results of the landscape-level metric analysis of the three LUI levels are summarized in Table 3. With increasing LUI, ED increases from 17.94 to 26.59. The reduction of AREA (from 153.20 to 93.25) and LPI (from 47.54 to 24.62) from low LUI to high LUI indicates that patches become smaller during the land development process. The decrease of the SHAPE index (from 1.79 to 1.63) from low LUI to high LUI indicates that patches share proportionally less edge with each other in high LUI than in low LUI. The increase of the ECON index (from 69.33 to 73.14) from low LUI to high LUI indicates that the ecological attribution of patch and adjacent patches had more difference in high LUI region than low LUI. Also, the decrease of MESH with increasing of LUI indicates that high land development exacerbates the fragmentation of landscape in high LUI regions.

Relationship between land-use intensity and ecosystem services

As shown in Fig. 3, a clear difference in ecosystem services was found between three LUIs. Crop production was lower for low LUI and higher for high LUI and there was a significant difference between low and high LUI (Fig. 3). However, correlation analysis results (Table 4) showed that crop production was positively correlated to LUI scores.

Two regulating services, soil conservation and climate regulation, presented a similar change trend. As the LUI increased, there was a decrease in soil conservation and climate regulation. Two regulating services of low LUI towns were significantly higher compared to towns with a high LUI. In addition, the correlation analysis results (Table 4) showed that two regulating services both had a negative correlation with the LUI value.

Relationship between land-use intensity and human well-being

The standard of living and food security well-being showed opposing change trends with increasing LUI. Lower living standards were found in low LUI region, while higher living standards were found in high LUI region and there was a significant difference between low and high LUI (Fig. 4). For the food security human well-being (disaster-

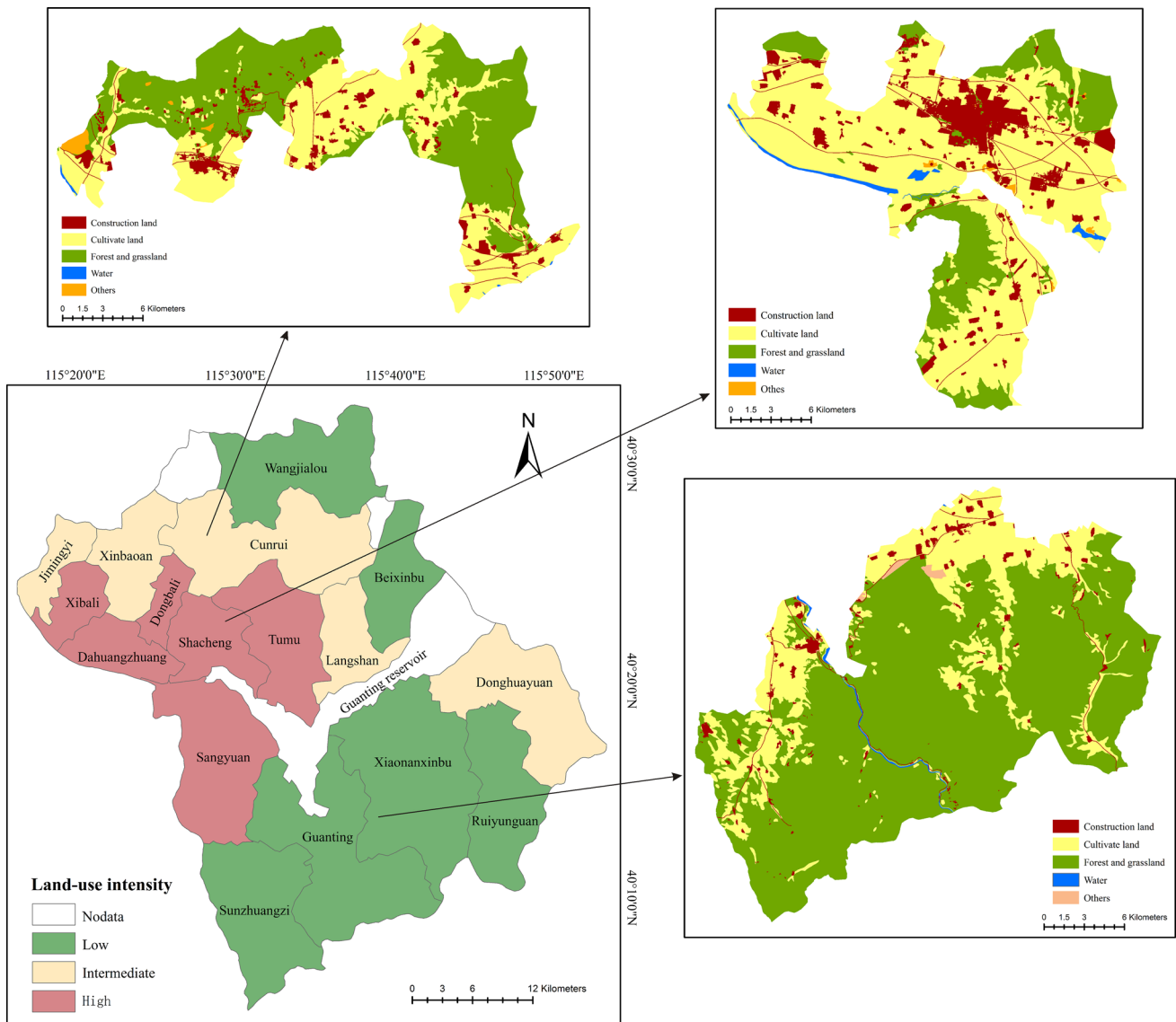


Fig. 2 Spatial distribution of land-use intensity (LUI) of Huailai in 2010

Table 3 Landscape metrics changes of different LUI at the landscape level

LUI	AREA_MN (ha)	LPI (%)	ED (m/ha)	SHAPE_MN	ECON_MN (%)	MESH (%)
Low	153.20	47.54	17.94	1.79	69.33	17,793.24
Intermediate	97.00	23.92	24.94	1.72	75.01	4,263.89
High	93.25	24.62	26.59	1.63	73.14	3,790.77

damaged loss of crop yield, higher loss indicated less safety well-being), the low LUI level corresponded to higher security, and high LUI towns demonstrated less security. The difference of food security between three LUI is not significant. The correlation analysis results showed that the LUI scores were positively correlated to living standards, while the correlation between the LUI value and food security was not-significant.

Relationship between ecosystem services in the context of land development

As shown in Fig. 5, provisioning and regulating services presented opposing changing trend with increasing LUI. The provisioning service increased with increasing LUI, while regulating service decreased (Fig. 5). According to the correlation analysis results, we found a strong positive

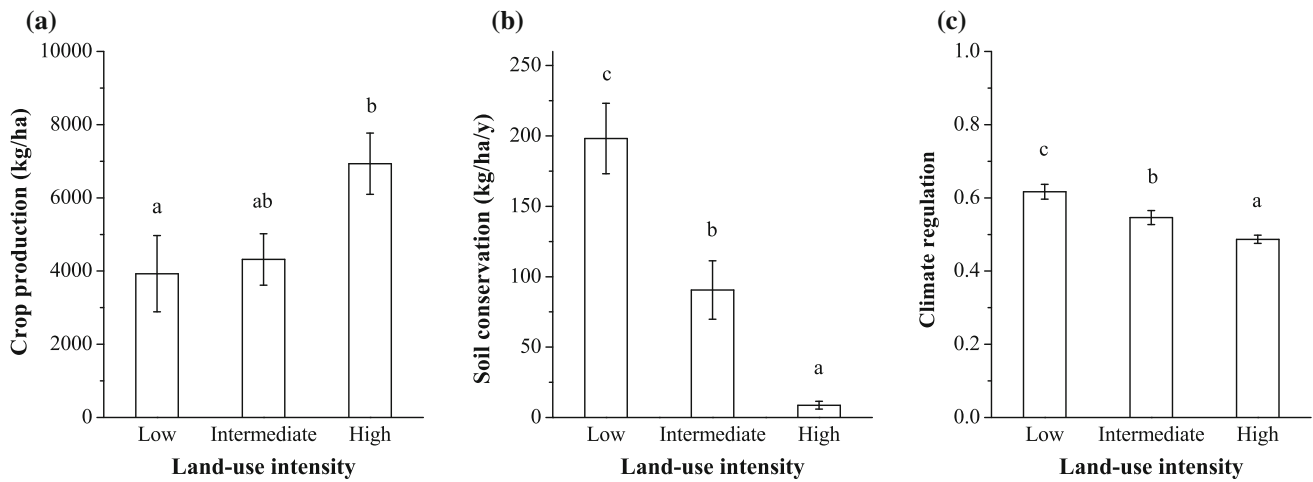


Fig. 3 Means and standard err of ecosystem services in different land-use intensity (LUI) of Huailai, 2010; **a** provisioning services—crop production; **b** regulating service—soil conservation; **c** regulating service—climate regulation. Information about the indices of ecosystem services can be found in Table 2. No-significant differences between LUI are identified with identical letters

Table 4 Significant spearman rank correlation coefficients between land-use intensity (LUI) and ecosystem services and human well-being proxy data

	LUI	Crop production	Soil retention	Climate regulation	Rural per capital net income	Reduction in grain yield
Driver						
LUI	–					
Crop production	0.620 (0.008)**	–				
Ecosystem services						
Soil retention	–0.904 (0.000)**	–0.628 (0.007)**	–			
Climate regulation	–0.814 (0.000)**	–0.561 (0.019)*	0.876 (0.000)**	–		
Rural per capital net income	0.576 (0.016)*	0.735 (0.001)**	–0.531 (0.028)*	–0.554 (0.021)*	–	
Human well-being						
Reduction in grain yield	0.13 (0.618)	0.185 (0.476)	–0.179 (0.476)	–0.295 (0.251)	0.291 (0.256)	–

* Coefficient is significant at the 0.05 level

** Coefficient is significant at the 0.01 level

correlation between regulating services (soil conservation and climate regulation), and regulating services were negatively correlated with provisioning service.

Discussion

Relationship between provisioning and regulating services

The negative correlation between provisioning and regulating services indicated that there were tradeoffs between provisioning and regulating services. Towns with high food production always had a low level of soil retention and climate regulation capacity. The correlation results among

ecosystem services were caused by the spatial incompatibilities of the landscape. In towns located in the plains area, where the major land-use was cultivated land, the food production capacity was strong and soil retention and climate regulation decreased. In contrast, towns located in mountainous areas, where the main land-use classes were grassland and forest, held strong regulating services and crop provisioning services were decreased.

In addition, a positive correlation between soil conservation and climate regulation indicated that there was a synergy between two regulating services. The synergy relation between regulating services has been indentified at different scales (Egoh et al. 2008; Jia et al. 2014; Raudsepp-Hearne et al. 2010a). Egoh et al. (2008) found that soil retention has synergistic relationship with the surface

Fig. 4 Means and standard error of human well-being in different land-use intensity (LUI) of Huailai, 2010; **a** standard of living-net income of rural residents; **b** food security–disaster damaged loss of crop yield. Information about the indices of human well-being can be found in Table 2. No-significant differences between LUI are identified with identical letters

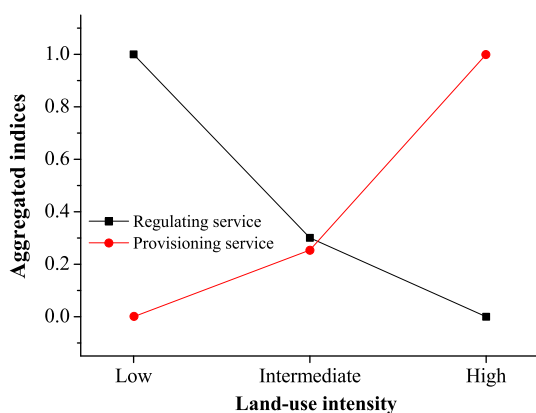
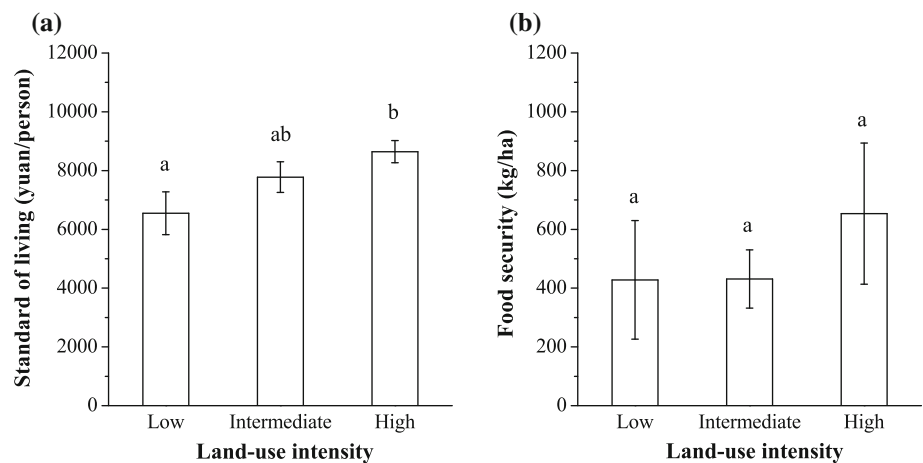


Fig. 5 Provisioning and regulating services of different land-use intensity (LUI) of HuaiLai, 2010

water supply and soil accumulation. Moreover, correlations between primary productivity and other regulating services were moderately strong and mostly positive. A decrease in a specific regulating service is often accompanied by a decrease in other ecological functions. The spatial heterogeneity of ecosystem services and their interactions suggest that the sustainability of ecosystem service production requires regional-scale management. In addition, an understanding of the heterogeneity and interactions of ecosystem services can identify areas where ecosystem management has produced exceptionally desirable or undesirable sets of ecosystem services.

Relationship between land-use intensity, ecosystem services and human well-being

The different trends of provisioning and regulating services with increasing LUI indicated that increasing LUI resulted in tradeoffs between provisioning and regulating services. High intensity land-use increased the crop production and decreased the regulating services of the study area. The

tradeoff relationship between provisioning and regulating services of this study was consistent with the findings of previous correlation studies (Egoh et al. 2008; Jia et al. 2014; Raudsepp-Hearne et al. 2010a). However, importantly, regulating services underlie the sustainable production of provisioning and cultural ecosystem services (Bennett et al. 2009; Rodriguez et al. 2006). The results of the relationship between provisioning and regulating services in this paper indicates that the food production of the study area is currently not affected by these tradeoffs. The steady decrease in regulating ecosystem services often go unnoticed until it is surpassed by their associated thresholds, which undermine the sustainability of provision and directly affects local human well-being (Bennett et al. 2009; Ehrlich and Goulder 2007). For example, agricultural production is strongly dependent on water resources and soil fertility, and increasing trends of crop production will not last very long when the water and soil quality continuously decline. Thus, a threshold of LUI will be reached in the process of land development, and this type of pattern, which exchanges regulating services for material provision, is unsustainable.

Several studies have indicated that a decrease in regulating services is accompanied by a decrease in the diversity of ecosystem services (Egoh et al. 2008). As the intensity of land-use increase, natural landscape is gradually replaced by construction and cultivated land. Ecosystems become simplified, and then, regulating services and the diversity of ecosystem services both decline. In addition, the LMs analysis of different LUI indicated that land development resulted in landscape fragmentation. The high LUI regions had smaller patches and greater edge density, revealing that the core area of habitat was decreasing and sensitive edge area was increasing. Ecosystems become simplified and fragmented, and then regulating services and diversity of ecosystem services both declined. To improve the regulating services of the towns that have high

LUI, it is necessary to constrain land development and increase the amount of green space. Green spaces are important habitats of species and ensure biological diversity and ecosystem services. In areas where land-use pressure is considerable, regulating ecosystem services can be secured by leaving green areas in close proximity to one another (Niemela et al. 2010).

Drought is the main natural disaster that reduces the crop production of the study area. Evidences that increasing agricultural droughts are already emerging in northern China, which generally experiences higher temperatures (Tao et al. 2006). In high LUI region, droughts cause a great loss in crop production. Abiotic and biotic stresses in high LUI areas may enhance the vulnerability to drought. Soil erosion results from poor field management and unreasonable land-use subsequently cause water and nutrient losses. A decline in regulating services would increase the vulnerability of productivity to climate change (Midmore et al. 1996). Sufficient irrigation water and fertile soil are important to reduce the loss from droughts. Some agricultural management strategies can be applied to cope with changing climatic conditions. Farmers can also conserve soil moisture by mulching between plants or planting drought-resistant plants to substitute for water-demanding crops (Simelton et al. 2009; Zhang et al. 2007). In particular, tillage has proven to be helpful in reducing soil erosion (De la Rosa et al. 2000). Improvement of water harvesting methods can also contribute to the reduction of the vulnerability to drought (Simelton et al. 2009).

As LUI increased the security of agricultural production decreased. However, statistical analysis showed that this relationship is not significant. There are many factors that could contribute to the complicated relationship between LUI and human well-being. Although LUI has a strong correlation with ecosystem services in this study, the relationship between ecosystem services and human well-being is complicated. Technology decouples well-being from nature. The dependence of human well-being on natural ecosystems has been significantly reduced over time. Moreover, there is a time lag between the changes in ecosystem services and human well-being (Raudsepp-Hearne et al. 2010b). In any case, limited research scale restricted our study from determining the complicated connection between LUI and human well-being.

Implications

Rural residents in China account for approximately half of the total population. The sustainable development and human well-being of rural areas are very important. Our findings revealed the effect of LUI on various ecosystem services and human well-being in one Chinese mountainous county. High intensity development of land resources has a

positive effect on crop production and resident income and negative effect on regulating services and the resistivity of agricultural system to droughts. Our study also revealed the spatial heterogeneity of LUI and the divergent responses of various ecosystem services and well-being to increasing LUI. These findings illustrate the complicated relationship between human activity, ecosystem services and human well-being in spatial scale (Duraiappah 2011; Raudsepp-Hearne et al. 2010b). Furthermore, disaggregation analysis was performed to reveal the complicated relationship between human activity and ecosystem services and human well-being (Daw et al. 2011). Thus, the findings and analysis framework in this study provide guidelines for creating scientific land-use policies to improve the well-being and ecosystem services of the study area.

In this paper, the measuring method of LUI adopted in this study was singly based on one proxy indicator. Although the land-use based indicator effectively estimated the spatial distribution of LUI in study area, a comprehensive measuring method is required to involve the multidimensional nature of LUI in future studies (Erb et al. 2013). Additional research should also be performed to explore the linkage between LUI and cultural services and other indicators of well-being, such as life expectancy, literacy and health. Irrespective of the calculation method, the statistical relationship between the sensor signal and the data derived from field observations is affected by the sensor characteristics like spectral, spatial and temporal resolution (Ayanu et al. 2012). Moreover, multiple boundary conditions like time of the day and year, actual state of ecosystem components, and the atmosphere also affect the statistical relationship and reduce its validity for monitoring and spatial transfers to other study area (Ayanu et al. 2012). Also, Barrachina et al. (2015) warn that NDVI will give poor information about the biophysical properties of vegetation when the background is unknown. Therefore, in situ measurements are needed for validation when using remote sensing data.

The scale of the analysis partially determined the results of this study (Raudsepp-Hearne et al. 2010a). Thus, an appropriate next step would be to expand the geographic scope of the analysis to other contexts, such as urban areas, rural areas located in plains area, or areas with a larger LUI gradient. These studies may investigate and improve the comprehension of the relationship between LUI and ecosystem services and human well-being.

Conclusions

In Hualai County, a Chinese rural watershed, increasing LUI has a positive correlation with crop production and living standard well-being and a negative correlation with

soil conservation and climate regulation. In addition, the relationship between LUI and food security is not significant. As LUI increases, there are tradeoffs between provisioning (crop production) and regulating services (soil conservation and climate regulation) and the synergistic degradation of regulating services. Understanding of the different responses of ecosystem services and human well-being to increasing LUI and the interactions between different ecosystem services is important for decision-making to improve human well-being and the provision of multiple ecosystem services in the study area.

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