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Spatial identification of land use multifunctionality at grid scale in farming-pastoral area: A case study of Zhangjiakou City, China

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ABSTRACT

Land use mutilfunctionality (LUMF) has recently received increasing attention in scientific and policy contexts because its capacity to bridge the connections between mutilfunctionality and land uses, as well as to integrate production, living and ecology approaches in policy development. This study established a conceptual framework for identifying and evaluating LUMF in spatial grid context from the perspective of structure, function, and well-being. Embedded in the spatial reference framework, a set of spatialization models were applied to quantify and visualize land use functions (LUFs), e.g. production, living, and ecology functions, by using multi-source and multi-scale data (land use data, remote sensing data, meteorological data, and statistical data, etc.) in Zhangjiakou City. The interactions of LUFs were measured, and on this basis, land use zoning was proposed. The results showed that the functionality indexes of production, living, and ecology ranged from 0 to 0.500, 0 to 0.994, and 0 to 0.998, respectively. The high production and living functions, and the low ecology function mainly occurred in well-developed regions, especially in the city center, where existed the strong synergies between production and living functions, as well as the strong trade-offs between the above two functions and ecology function. The low production and living functions, and the high ecology function were mainly distributed in mountain and hilly areas, located in the eastern and southern parts, where existed the weak synergies between production and living functions, and the strong trade-offs among production, living, and ecology functions. Four categories of land use zones were divided at town-level, namely, ecological preservation zones, urbanization development zones, agricultural production zones, and countryside improvement zones, mainly based on the spatial distribution of the synergies and trade-offs among LUFs. This study provides a pathway for quantitatively evaluating LUMF, and making land use zoning division, which provides quantitative information for policy-makers to implement land use optimization, economic development, and ecological protection in the light of the interactions of LUFs.

1. Introduction

Multifunctionality concept originated from the agriculture sector, referring to the simultaneous provision of diverse outputs and the consequent satisfaction of multiple demands (Callo-Concha & Denich, 2014; Marshall & Moonen, 2002; Wiggering et al., 2006). In the context of pursuing sustainable development, multifunctionality research has extended from agriculture to economy, society, environment, as well as sustainable land use assessment (Kates et al., 2001; Zhou, Xu, & Lin, 2017). With the boom in Global Land Programme (GLP), the concept of multifunctionality is given further importance to sustainable land development, making multifunctional land use, and sustainable development of society, economy and ecology become a new concern of land system science (Sal and García, 2007; Paracchini, Pacini, Jones, & Pérez-Soba, 2011; Nguyen et al., 2015).

Land use functions (LUFs) are perceived as the private and public goods and services provided by the different land uses that summarize the most relevant economic, environmental and social aspects of a region (Kienast et al., 2009; Pérez-Soba et al., 2008), which was spurred by European project 'Sustainability Impact Assessment: Tools for Environmental Social and Effects of Multifunctional Land Use in Europe Regions (SENSOR)'. Land use multifunctionality (LUMF), namely, the

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diversification of land use function, is a status and expression of LUFs simultaneously having multiple economic, social and ecological functions (Zhen et al., 2010). LUMF is generally indicated by LUFs (Du, Sun, & Wang, 2016; Verburg, Steeg, Veldkamp, & Willemen, 2009; Zhang, Zhu, & Xu, 2014). Healthy land use system possesses not only structural integrity, but also functional continuity and additivity (Schluessel, Bennett, Bleckmann, Blomberg, & Collin, 2008). The unbalance among social, economic, and environmental LUFs will result in environmental pollution, energy resources overexploitation and ecosystem degradation. Thus, it has become an important issue to satisfy human diversified demands for the limited land resource through multifunctional land use (Liu, Liu, & Chen, 2011; Steinhäußer, Siebert, Steinführer, & Hellmich, 2015).

LUMF research has obtained an increasing attention in scientific and policy debates on the future of sustainable development. To balance the three dimensions of sustainability, SENSOR project proposed a conceptual framework of regional sustainability assessment from the perspective of LUFs (Pérez-Soba et al., 2008), and 9 LUFs characterized by a set of economic, environmental and social culture indicators were chosen. Consequently, this project converted European Union assessment into the comprehensive regional impact assessment (Hermanns, Helming, Schmidt, König, & Faust, 2015), greatly promoting the application of LUMF methodology in the field of land use sustainability impact assessment. For example, Zhen et al. (2009) established a conceptual framework to assess Chinese LUFs, and then, Xie et al. (2010) improved it by taking into account policy scenarios and detailed subdivisions of land use. Reidsma et al. (2011) applied the concept of LUFs for the sustainability impact assessment, and discussed the impacts on these LUFs with stakeholders in developing countries. Purushothaman et al. (2012) adopted LUFs framework in the participatory impact assessment to address multidimensional sustainability in agricultural landscapes. However, despite the increase in publications on LUMF, a comprehensive framework for LUMF assessment remains partial and incomplete (Liu, Xu, Sun, & Liu, 2016). Additionally, the classification of LUFs is the basis of LUMF assessment, and LUFs have been classified into three main functions, i.e., economic, social, and environmental functions (Du et al., 2016; Paracchini et al., 2011; Wang & Dong, 2015; Xie et al., 2010), or production, living, and ecology functions (Sun, Xu, Liu, Liu, & An, 2017; Zhang, Zheng, Yuan, & Cui, 2016; Zhou et al., 2017), representing sustainability dimensions. There does exist the corresponding relationship between land use function and land use type/structure, so LUFs are also divided into production, social, and ecology functions according to land use types (Li, Zhang, Lv, & Dong, 2011; Liang, Gu, Lei, & Wang, 2014). However, it is still sketchy and insufficient to equate land use function with land use type/structure, because land use type/structure was the explicit form of land use, whereas the function emphasize more on its implicit property (Liu, Long, Li, & Tu, 2015; Long, Liu, Hou, Li, & Li, 2014). Therefore, to truly realize and model the complexity of LUFs and land use types is urgently needed.

LUMF research is also struggling with the spatial identification, and quantification of multiple functions at the grid-level due to a lack of knowledge on land use functioning (Liu, Duan, Wang, & Zeng, 2010; Liu et al., 2018). The majority of literature focused on classifying and assessing LUMF by constructing evaluation index systems at administrative unit scales (Huang et al., 2017; Paracchini et al., 2011), such as the whole country (Helming et al., 2008; Xie et al., 2010), province (Du et al., 2016; Zhang et al., 2014), prefecture-level city (Wang & Dong, 2015; Wang & Zhen, 2017; Zhang et al., 2016), and county scales (Liu et al., 2011; Sun et al., 2017), etc. For example, Zhen et al. (2010) identified 10 relevant LUFs for China, and analyzed their spatial and temporal changes in 31 provinces and municipalities from 1985 to 2005. Wang and Dong (2015) measured the change of LUFs, as well as their obstacle indicators during 1990–2010 in Guangzhou City. Du et al. (2016) comprehensively examined the spatiotemporal patterns of multifunctionality of land use from 1990 to 2013 in Northeast China. Sun et al. (2017) explored the spatiotemporal differentiation characteristics of LUMF and its influencing factors in poverty belt around Beijing and Tianjin in county scale. With these progresses, however, a problematic undermining of many investigations is that index data mostly derived from socioeconomic data, making the evaluation unit is currently limited to administrative regional level. Moreover, spatial information of land use function is scarce since only some directly are in relation to the observable land use productions, while others depend on additional intensive field observations or cartographic work. Hence, at the grid scale, in-depth research on an integrated assessment of LUMF fusing multi-source and multi-scale data, as well as the trade-offs between different functions ought to be carried out.

It is worthy of note that the notion of LUMF should not be confused, for example, with the idea of 'landscape multifunctionality', which is described as the co-existence of ecological, economic, cultural, historical and aesthetic functions provided by landscape (Katriina, 2001; Peng, Chen, Liu, Lü, & Hu, 2016a). LUMF is the result of a theoretical and conceptual evolution of agriculture multifunctionality, ecosystem services, and landscape multifunctionality. However, the above two conceptions are different in term of the definition, method, perspective, as well as application. In other words, these differences can be attributed to the dissimilarity between land use function and landscape function. Firstly, with regard to the term definition, landscape function is always used to describe the ability of the landscape to provide goods and services to human society (Mastrangelo et al., 2014; Willemen, Verburg, Hein, Martinus, & van Mensvoorta, 2008), emphasizing the composite nature of the landscape's capital stocks (Kienast et al., 2009; Křováková, Semerádová, Mudrochová, & Skaloš, 2015). However, the notion of land use function describes more the flows of social, economic and ecological benefits that land may generate (Helming et al., 2008; Kienast et al., 2009). Secondly, landscape function is generally valued by currency unit (Jose, 2009), and is assessed by index system (Rodriguez, Alday, & Onaindia, 2015), or spatial models (Peng et al., 2016a). While land use function is mainly mapped by index system or land use types (formations). Moreover, as for research perspective, landscape function, developed from ecosystem services (Willemen et al., 2008), is often conceived and assessed as the joint supply of multiple ecosystem services at the landscape level (Mastrangelo et al., 2014). As a result, landscape function is substantially biased towards the (semi-)natural pillars, while land use function mainly focuses on human needs, and simultaneously reconciles with nature (Liu et al., 2016), assessing the direct impact of land use change on the economic, social and environmental dimensions of sustainability (Pérez-Soba et al., 2008). Lastly, with roots in the field of landscape ecology and planning, landscape function is developed and used in functional evaluation of rural landscape (Ren, Liu, Sun, Yuan, & Zhou, 2018; Xie, 2004), urban landscape functions planning (Peng, Wang, Jing, Song, & Han, 2005), and county-level development zoning (Peng et al., 2016a). Nevertheless, land use function approach is still sketchy in practice, developed more specifically for regional sustainability assessment (Pérez-Soba et al., 2008), land use zoning (Chen & Yang, 2012), and internal structure classification of rural settlement (Ma, He, Jiang, Li, & Zhang, 2018). With the meticulous and diversified management of land resources, it is inevitable to spatialize land use functions from a comprehensive perspective at the micro-scale. Therefore, the approach for land use zoning based on LUMF is urgently needed if we are to achieve sustainable land use.

Zhangjiakou City (hereinafter Zhangjiakou) is a part of farming-pastoral ecotone in Northern China (Sun et al., 2016), which is faced with the tasks of economic growth, social welfare, and ecological protection. Along with the development of the integration of Beijing, Tianjin, and Hebei Province, social economy in Zhangjiakou has developed rapidly, which provokes the intense conflicts of land supply and demand, and imposes a heavy pressure on local resources and eco-environment. And undoubtedly, the change of land uses is also causing the corresponding change of the functions. Therefore, taking