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Multi-dimensional eco-land classification and management for implementing the ecological redline policy in China

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ABSTRACT

The ecological civilization characterized by the ecological redline policy (ERP) has been a new long-term national development strategy in China. The ERP emphasizes the need to define ecological baseline areas to provide ecosystem services and guarantee the national ecological safety. Eco-land units delineated by the individual spatial boundaries of ecosystems may facilitate an understanding of ecosystem patterns and the associated ecological processes at the landscape level. An eco-land classification system may help to identify and manage ecological baseline areas. In this study, a multi-dimensional eco-land classification system was designed to show how eco-land types could provide a reliable work platform for implementing the ERP and land management. Based on previous studies of eco-land types, we extracted three characteristics comprising the scale dependence, functional dominance, and adaptability of management. These three features were then integrated with the existing land use classification to develop a hierarchical eco-land classification system with four primary classes (fundamental eco-land, auxiliary eco-land, productive eco-land, and daily-life eco-land), 11 secondary classes, and 21 sub-secondary classes. Using a performance index based on spatial overlay analysis, we found that the fundamental eco-land covered up to 65% of the ecological redlining areas at the national scale, but not in some physical geographical regions. Thus, productive eco-land, auxiliary eco-land, and daily-life eco-land were also classified to fill the national level gaps among fundamental eco-lands, where the percentage cover of eco-land types at both the regional and urban scales could exceed 65% of the ecological redlining areas at the corresponding scale. Therefore, the disconnected fundamental eco-lands within ecological redlining areas at the national scale might be linked together as a conterminous green infrastructure if productive, auxiliary, and daily-life eco-land types located in strategic gap sites can be identified and protected at regional and urban scales. The eco-land classification system developed in this study may provide a useful land management framework for implementing the new ERP in China.

1. Introduction

China is the largest developing country in the world and it has been going through a rapid period of urbanization with fast population growth, which has been accompanied by thriving economic development and increasing demands for natural resources. Thirty years of rapid urbanization in China has resulted in severe ecological consequences including resource depletion, environmental pollution, and ecological degradation (Fu, 2008; Fu et al., 2012; Wang et al., 2012; Liu et al., 2014; Zhao et al., 2014; Chang et al., 2015), as demonstrated by the increased risks of flooding and hazy weather, public health concerns, biodiversity losses, reduced food and water security, as well as other undesirable social and economic consequences (Shi et al., 2011; Fu et al., 2012; Bai et al., 2016).

In order to mitigate ecological degradation and maintain ecosystem services, the Chinese government has proposed the strategy of ecological civilization, i.e., existing in harmony with natural systems instead of trying to overwhelm and dominate nature (Magdoff, 2011), as the new long-term national development strategy in China (The 18th National Congress of the Communist Party of China, 2013). A series of nature conservation and ecological restoration programs have been implemented since the late 1990s, including the Three-North Shelter Forest Program (Jiang et al., 2009), the Wildlife Conservation and Natural Reserve Program (Ouyang, 2007), the Grain to Green Program

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Table 1
Descriptions of the main ecological redlines existing in China.

Name	Targets	Sources
Key Ecologically Function Zones (KEFZ)	-Fifty zones with a total area of 2.34 million km^2 (24.3%) -With the spatial location, but not the redlining boundary	Ministry of Environmental Protection (MEP) and Chinese Academy of Sciences MEP and CAS (2015)
Arable Land Redline (ALR)	-Minimum area of croplands is 120 million km^2 -To ensure the amount available and improve the quality -No spatial redlining at present	Ministry of Land and Resources MLR (2009)
Major Function-oriented Zones (MFOZ)	-Development prohibited zones (DPZ, 12.5% of the national territory) -Development restricted zones (DRZ, 40.2% of the national territory), including the major production regions (MPR) -With the spatial location, but not the redlining boundary	The State Council of China (2010)
Water Resource Redline (WSR)	-Total amount of water utilized < 700 billion m^3 -Effective coefficient for irrigated water > 0.6 -Added value of industrial water < 0.04 m^3/RMB -Main pollutant compliance rate in water function area > 95% -No spatial redlining yet	Ministry of Water Resource MWR (2012)
Ecological Redline Policy (ERP)	-Ecological service hotspots such as water supply areas -Ecological fragile hotspots such as soil erosion areas -Biodiversity hotspots such as endangered wildlife habitats -No spatial redlining at present	Ministry of Environmental Protection MEP (2015)

(Liu et al., 2008), and the redline paradigm (Lü et al., 2013). Among these policies, the redline paradigm is considered to be the strictest ecological conservation measure implemented in China (Lü et al., 2013; Bai et al., 2016). However, several of the ecological redlines (Table 1) proposed in the last decade have not been very successful, as follows. (1) The arable land redline (ALR) and water resource redline (WSR) were set to limit the minimum area of arable land and the total volume of water utilization, respectively, but without defining explicit spatial boundaries, and this lack of spatial information caused some unanticipated problems (Lü et al., 2013; Bai et al., 2016), e.g., farmlands are currently expanding but their quality is declining in China (Wang et al., 2012; Bai et al., 2016). (2) The development prohibited zones belong to the major function oriented zones (MFOZ) and the key ecologically functional zones (KEFZ), and they play key roles in soil and biodiversity conservation, water provision, flood mitigation and desertification control (Lü et al., 2013; Bai et al., 2016). These zones are biodiversity hotspots, eco-services, or eco-fragile hotspots, and they provide spatial guidelines for ecosystem management and ecologically friendly socioeconomic development (Lü et al., 2013). However, both of these types of zones only have spatial locations and they lack corresponding management spatial units, especially land units, so they have been diluted to help determine the ecological redline, although they must be considered according to the ecological redline policy (ERP) implemented in 2014. Thus, *the Technical Guideline for Delineating Ecological Redlines* was released to meet the increasing management needs of "where and why to protect" (Zheng and Ouyang, 2014; Bai et al., 2016). This technical document explains how to delineate the ecological redline to preserve ecosystem services, and well as clearly specifying "eco-land" in ecosystems as the spatial unit for the ecological baseline area (MEP, 2015).

However, there is still no common agreement about the definition of eco-land, although this terminology has been listed in the national political agenda of China since the 2000 s (Zhang et al., 2016). Originally, the usage of the terms "eco-land" started in western countries, such as Canada, the USA (Sims et al., 1996), and United Kingdom (Bunce et al., 1996), but this terminology has been used more widely in China than other countries since 2003 (Fig. 1). As shown in Fig. 1, two years after the "Global to local: ecological land classification" international conference held during August 15–18, 1994 in Canada, 43 related studies were published (Sims et al., 1996) and the amount of studies published by non-Chinese scholars increased significantly subsequently. Non-Chinese researchers classified lands ecologically (Zonneveld, 1995; Bunce et al., 1996; Hanson and Hargrave, 1996; Dale et al., 2000; Capotorti et al., 2012; Steenberg et al., 2015; Uddin et al., 2015) and identified land units to consider ecological functions or ecosystem services for land conservation (Smith and Carpenter, 1996; Carter et al., 2014) and to enhance human or ecosystem health (Marulli and Mallarach, 2005; Weber et al., 2006; Wickham et al., 2010; Pino and Marull, 2012; Shoyama et al., 2013; Kennedy et al., 2016; Oliveira et al., 2017), and as well as for sustainable land use (Ellis et al., 2010; Atik et al., 2015; Spanòa et al., 2017), although the term "eco-land" was not referred to directly. Nowadays, Green Infrastructure (GI) has been introduced to upgrade ecological lands as a coherent network entity (Benedict & McMahon, 2002; Tzoulas et al., 2007). Instead, Chinese researchers first introduced the term "eco-land" in 1999 to refer to the spatial carriers of physical elements (e.g., vegetation, soil, and water) with various ecological protection functions (Dong et al., 1999). Subsequently, the term "eco-land" has been used widely in academia, among the public, and by the government in China (Fig. 1). Much research has focused on the amounts, structure, and optimizing the patterns of eco-land in given areas (Han et al., 2003; Li et al., 2005; Wang et al., 2012; Wu et al., 2013; Liu et al., 2014; Chang et al., 2015), estimating the ecosystem services and the eco-compensation mechanism (Zhang et al., 2004; Liu et al., 2008; Fu et al., 2012; Li et al., 2013; Zhao et al., 2014), as well as the concept and classification systems (Han and Wang, 2003; Long et al., 2015; Yu et al., 2015). Therefore, it is now widely acknowledged by international academia that the ecological classification of land provides the opportunity to describe, characterize, and spatially locate various ecosystems and their services at the landscape scale.

In practice, the official classification system standard for land management in China is the system of *Current Land Use Classification* (SAC, 2007), which comprises 20 categories and 57 sub-categories (Appendix A). This system is based mainly on whether the land is used or not by humans, as well as the intensity of utilization. For example, land in use is subdivided into built-up land (e.g. commercial, industrial, residential land, administrative and public facilities, transportation, and water facilities), farmland, orchards, grassland, and forests. The economic and social characteristics of land are clearly indicated in this system, whereas the ecological features related to ecosystem services are ignored. Thus, land with significant ecological functions cannot be protected from intensive economic activities (Chen and Zhou, 2007). By contrast, the official standard for eco-land management, i.e., the system of *Urban Green Space Classification* (MHURD, 2002), divides eco-land into parks, garden nurseries, protective green spaces, attached green spaces, and other green spaces (Appendix B), where the first four types