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Original Articles

The evaluation of forestry ecological security in China: Developing a decision support system

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ABSTRACT

The development of modern science and technology tends to accompany environmental crisis and ecological degradation. And the evaluation of the security condition of the forestry ecosystem has become an urgent task. This paper details the development of a decision support system (the FESEDSS), which was built to provide a range of actors with an effective tool for the evaluation and governance of forestry ecological security in China. The FESEDSS considers multiple factors through a general decision-support framework, making possible the calculation of ecological security indexes and relative indexes for the forestry ecosystem and its three subsystems (forest, wetlands and desert) at both the national and provincial level. The system integrates econometric models, mathematical methods, geographic information systems and a dynamic database, providing users with an understanding of spatiotemporal patterns and regional differences in the ecological security of the forestry ecosystem and its three subsystems in China's 31 provinces. Results generated using the FESEDSS and addressing the period 1999–2012 demonstrate a positive change in forest ecological security condition and a negative change in wetland and desert ecological security. Spatially, the ecological security of the forest subsystem was shown to have improved significantly in eastern and central China, while in the western region it experienced degradation. The ecological security of wetland ecosystems performed well in the southwest region and the middle and lower reaches of the Yangtze River; and desert ecological security was shown to be of a higher standard in south of Qinling-Huaihe Line than in the northern regions of the country. The overall forestry ecological security condition (which integrates the three subsystems) demonstrated an upward trend with some fluctuations, with high values generally being located in the south and low values in the north of the country. Finally, the paper also discusses performance, uncertainty, and implementation challenges, as well as detailing potential extensions of the FESEDSS. The paper lays a foundation to the national forestry ecological security evaluation and monitoring.

1. Introduction

China is a populous country with a vast territory and a tremendous diversity of biological resources. In recent years, however, its forest ecosystems have begun to suffer severe degradation as a result of human disturbances of differing durations, intensities, frequencies and types (Dai et al., 2006). A large proportion of the country's wetlands have been converted to industrial, agricultural and construction land uses; this, in combination with environmental pollution and an excessive utilisation of resources, has in turn led to reductions in the quality of wetlands and a marked decrease in biodiversity. Human activities such as the overexploitation made possible by land reclamation, practices of overgrazing and the degradation of water resources have all further contributed to advancing land degradation and soil erosion, a trend ultimately linked to a soaring rate of desertification. In order to resolve the ecological problems addressed above, China's central government has put forward a series of policies and schemes to improve ecological security. Environmental protection forms one of the

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country's basic national policies, and the government has also mapped out a number of important strategies to realise sustainable economic development.

Ecological security is one of the most important aspects of environmental protection. Maintaining ecological security has become a critical task for human societies, in our attempt to achieve sustainable development in the 21st century (Wang et al., 2014; Li et al., 2014). The "forestry ecosystem" – a term put forward here to describe the management of not only forest ecosystems but also wetland and desert ecosystems – guarantees the biological function and terrestrial eco-environment of the earth (Lu et al., 2002). The higher the level of stability and security within the forestry ecosystem, the greater the level of protection it in turn can offer in relation to the environment as a whole. The evaluation of the security condition of the forestry ecosystem has thus become a hot topic in the research community. An urgent task exists in establishing a decision support system to effectively evaluate the ecological security of forests, wetlands and deserts and scientifically extends the results of such evaluations via practical applications.

A Decision Support System (DSS) is a technology for assisting users' decision making through identifying problems, collecting and analysing data, obtaining solutions and providing information (Antunes and Costa, 2012). A DSS often consists of various environmental models, databases and assessment tools, which are integrated through a graphical user interface (GUI) (He et al., 2006; Matthies et al., 2007). Current studies that use DSS technologies suffer from a number of deficiencies. Firstly, in terms of method, a DSS often comprehensively integrates the functions of geographic information systems (GIS) (Bouroushaki and Malczewski, 2010; Karnatak et al., 2007; Malczewski, 2006), multi-objective programming models (Chang et al., 2008; Chen et al., 2010; Papadopoulou-Vrynioti et al., 2013; Rahman et al., 2012; Zucca et al., 2008) and system optimization models (Huang et al., 2010). Whilst this capacity for integration allows for the effective synthesis of different types of information through scientific approaches to development planning, few current studies have integrated different types of methods into a DSS framework. Secondly, in terms of its practical applications, DSSs have been widely used in the study of industrial water pollution and treatment (Zhang et al., 2013), watershed pollution and management (Maksimović and Makropoulos, 2002), the sustainable use of energy (Santoyo-Castelazo and Azapagic, 2014), urban traffic planning (Ortega et al., 2014), water saving measures in agriculture (Massei et al., 2014), the planning and development of rural electrification (Agalgaonkar et al., 2006) and the construction of ecological modes of agricultural development (Scott et al., 2014). Such systems have, however, rarely been used in studies of forestry ecosystem, or the evaluation and governance of forestry ecological security. Thirdly, most current studies have focused on specific, smaller-scale areas. For example, a DSS was used in relation to the protection of pine forests in Michigan's Northern Peninsula (Maclean et al., 1992), decisions about reasonable irrigation on India's plains (Sharma and Pathak, 2002), pollution control in the Black Sea (Maksimović and Makropoulos, 2002), the use of rural land and water in northern Thailand (Merritt et al., 2004) and the comprehensive planning of socioeconomic development and eco-environmental protection in Yongxin County, Jiangxi Province, China (Huang et al., 2010). Current research has thus largely ignored macro scales; only a few of them have focused on the national and provincial level (Hof et al., 1999; Hof et al., 2004).

Responding to these deficiencies, through the present study we set out to establish a more comprehensive and systematic research framework, which would use a DSS to integrate multi-disciplinary knowledge in order to obtain the scientific results needed to support more rigorous decision making in relation to the forestry ecosystem. The study thus addressed the evaluation and management of "forestry ecological security" (which included the ecological security of three subsystems: forest, wetlands and desert ecosystems) in China's 31 provinces (municipalities). First, we constructed an evaluation index system for the ecological security of forest, wetland and desert subsystems. In this way, we were able to not only evaluate the ecological security of the forestry ecosystem as a whole, but also to separately assess that of the three ecological subsystems. Secondly, we produced an integrated index evaluation system, which combined econometric models, mathematical methods, geographic information systems (GIS) and dynamic databases for ecological security evaluation. Third, we designed a user-friendly interface (called the FESEDSS), which makes it convenient for forest managers and decision makers to update data and conduct real-time monitoring of the ecological security condition of forests, wetlands and deserts. Fourth, we applied the FESEDSS to a real study case in order to demonstrate its feasibility in the evaluation of forestry ecological security for China's 31 provinces (municipalities), and the country as a whole.

2. Research method

2.1. Forestry ecological security evaluation index system

The FESEDSS – the forestry ecological security evaluation index system described in this paper – was constructed to serve the managers and decision makers of the State Forestry Administration of China (SFAC), the authority responsible for the forestry ecosystem and its forest, wetland and desert subsystems in China.

The forestry ecosystem is a significant part of the broader ecosystem, acting as an invaluable ecological, economic, aesthetic and cultural resource on which the earth's homeostasis relies. The forestry ecosystem (Bakuzis, 1969) in FESEDSS includes forests (Hao et al., 1999), but also wetland (Mitsch et al., 2009) and desert ecosystems (Havstad et al., 2006). In China, forest, wetland and desert ecosystems account for more than 70% of the total territorial area. The future of the world's forests is of considerable interest from a variety of perspectives, including global change and biodiversity conservation, and forest ecosystems provide services that are essential to maintaining life support systems across all scales, from the local level to the global level (Liebhold et al., 2017). Greenhouse gas regulation, water supply and regulation, nutrient cycling, genetic and species diversity, and recreation are only some examples of the services provided by forests (Ferretti, 1997). Wetland ecosystems are also extremely crucial natural resources, which perform functions such as seashore protection, flood regulation, underground water replenishment, fish and shellfish propagation, water purification, climate adjustment, and ecotourism destination development (Moreno-Mateos et al., 2012). Desert ecosystems have comparable capabilities in absorbing CO_2 and modulating global atmospheric CO_2 levels, and thus play an important role in the hydrological and biogeochemical cycles of the earth's ecosystem (Li et al., 2011).

Ecological security is a relatively new concept. Released in 1948, "Social Scientists Call for Peace" is considered the forerunner of modern international environmental safety research, and it was shortly followed by the United Nations Conference on the Conservation and Utilization of Resources in 1949, the first United Nations conference on natural resources (Trzyna, 1989). In 1989, the International Institute for Applied Systems Analysis (IIASA) put forward the concept of "ecological security". In a broader sense, ecological security refers to human life and the safeguarding of essential rights to live free from threat—it thus includes natural, economic and social ecological security. In a narrower sense, ecological security refers to the security of natural and quasi-natural ecological systems, thereby linking ecological systems to notions of environment security. Building on these notions, in this paper, we put forward the concept of "forestry ecological security" in order to describe the way in which, in a certain time and space, the forestry ecosystem itself can provide effective ecological, social and economic functions for human beings, and at the same time, in the case of external interference conditions such as natural disasters and human activity, continue to self-regulate and self-repair, maintaining its