Original papers

Design and implementation of an index calculation system for forestry ecological assessment in China

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ABSTRACT

In recent years, ecological issues have become increasingly serious with the development of modern society. An effective assessment for the ecological environment status is of great significance for the protection and construction of the ecological environment. We present the China Forestry Ecological Index Calculation System (CFEICS), which provides the quantitative measurement and qualitative evaluation for the forestry ecosystem status. However, a series of problems arises in the process of system design and implementation, including frequent changing of the ecological indicator system, low reporting rate but high error rate of ecological basic data, and long period and low efficiency of system development. To address the abovementioned problems, we first designed a database model by using a table-driven approach (TDA). Second, we implemented a reusable software system—the dynamic ecological data management system (DEDMS)—based on the TDA. The DEDMS contains data access, data verification, data statistics, index calculation, and index expression components. Third, we applied the DEDMS to the CFEICS and completed the final CFEICS. After practical test and application, the system was used as the official ecological index calculation system in Chinese forestry.

1. Introduction

Environmental issues began to attract the attention of the international community in the middle of the twentieth century (Underwood, 1962). After the 1990s, ecological problems such as rapid deforestation and climate change have increasingly aroused concern because of prominent cross-border global environmental hazards such as sandstorm, water pollution, air pollution, greenhouse effect, and El Niño (Degeest and Pirages, 2003). With the continuous development of modern society, the global scale of environmental problems has become one of the most difficult obstacles to overcome (Zhao et al., 2009), and every country has encountered different eco-environment problems (Chen et al., 2015). Therefore, accelerating the promotion of the protection and construction of the eco-environment is an urgent issue. Effective assessment of ecosystem status is the basis for the protection and construction of the eco-environment and plays an important guiding role in carrying out related work. Effective ecosystem assessment techniques can help environmental protection departments in overall planning, key construction, and comprehensive treatment (Yu et al., 2014). Ecological assessment results in different regions can improve the ecological security awareness of the entire population (Li et al., 2016).

At present, ecological evaluation is studied mainly from the aspect of ecological security or ecological carrying capacity. The concept of ecological security was presented by the International Institute for Applied Systems Analysis in 1989 (Qiu et al., 2008). Ecological security assessment theory has gradually matured over more than 20 years, but establishing scientific evaluation standards and a reliable indicator system remains a key aspect of relevant studies (Zhao et al., 2006). At present, ecological security assessment is applied to a specific region with small areas, and a generally accepted evaluation indicator system has not yet been formed (Huang et al., 2017; Lin et al., 2016). Quantitative evaluation and dynamic research of ecological security are still in the exploratory stage (Qiu et al., 2008). In 1921, Park and Burgess proposed the concept of carrying capacity (Xie et al., 2011). Subsequently, studies on carrying capacity have focused mainly on a single element, such as resources and the environment (Feng et al., 2008; Xie et al., 2011). With in-depth research, researchers began to pay more attention to comprehensive studies on carrying capacity considering the mutual influences and constraints of various objects in the ecosystem (Kailei et al., 2016; Li et al., 2011). However, no unified concepts and research methods are available for the study of ecological carrying capacity (Yue et al., 2015). By taking ecological security and ecological

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carrying capacity as the research objects, our team conducted a government-sponsored ecological index research beginning in 2013 to establish scientific evaluation criteria and a reliable indicator system to achieve a comprehensive ecological quantitative evaluation for the entire country. Over the past four years, we have established a set of ecological assessment methods, which have been used as the official forestry ecological assessment method in China. To effectively apply the forestry ecological assessment method to practical forestry work in China, we improved the traditional pressure–state–response (PSR) model (Cao et al., 2016; Ochola and Kerkides, 2004) to develop the forestry ecological indicator system. The forestry ecological assessment method includes forestry ecological basic data collection, indicator data calculation, indicator weight determination, ecological security index calculation, location coefficient (LC) calculation, ecological carrying capacity index calculation, and the release of ecological evaluation results.

In the forestry ecological index calculation, we used computer information technology to implement the forestry ecological assessment method. However, many practical problems need to be solved in the process of system design and implementation. First, the indicators in the forestry ecological evaluation indicator system (FEEIS) need to be constantly adjusted. Changes in the indicators cause related modules in the system, such as data collection, data calculation, and display modules, to change constantly. Therefore, we need to constantly modify the code and test procedures. However, the maintenance and extension of the system are difficult. Second, in the data filling stage, collected data are of low quality because of errors committed by workers who fill in data. Third, in the actual system development process, developing the system directly from scratch will lead to a slow speed, long period, low efficiency of system development, and cause considerable code redundancy in relevant areas. The rapid development of computer information technology provides a feasible new technical support to solve the abovementioned problems. The table-driven approach (TDA) is one of the most effective ways to improve the maintainability and scalability of the system (Yang and Parker, 2005). Researchers study TDA on the basis of a structural analysis of specific needs to simplify complex tasks and improve work efficiency (Junbin et al., 2009; Nadkarni and Marenco, 2010; Yang and Parker, 2007). Software reuse is commonly applied to improve the efficiency of software development and is also an efficient means to improve software maintainability (Kim et al., 2017). The application of reusable software can greatly reduce the waste of resources caused by the repeated design of software in related fields and can improve the standardization of software in the same field. The technology of reusable software has been widely used in aerospace (Ziemke et al., 2011), medical treatment (Fasquel et al., 2006), administration (Kwon et al., 2015), commerce (Ravichandran et al., 2013), and other fields. At present, many domain-independent studies and applications of reusable software framework are available (Wang et al., 2004).

To address problems in the design and implementation processes of the system, we first designed the working pattern of a data dispenser rationally to ensure that the collection rate of data meets the basic requirements. Second, we designed the relevant database with the TDA to provide a good solution to the series of problems caused by changes in indicators. Third, on the basis of the database model, we applied the accomplished reusable software—the DEDMS—to a forestry ecological index calculation project. The application of reusable software not only improves system development efficiency but also enables its series of internal common components to achieve the basic functions of data interaction, data validation, data statistics, index calculation, and index expression. Finally, we completed the China Forestry Ecological Index Calculation System (CFEICS), which is of good flexibility and practicality, thereby ensuring the effective implementation of ecological assessment methods.

2. Ecological assessment methods

In this work, we evaluate the ecological situation of a region on the basis of an assessment of the ecological security and the ecological carrying capacity for the ecosystem.

In China, forestry mainly includes three major ecosystems, namely, forest, wetland, and desert. We created an indicator system for every ecosystem by using the PSR model (Huang et al., 2017) and ultimately completed the total indicator system. To ensure the practical operability of the ecological assessment method, we reclassified the identified indicator system. We classified the response indicators in the PSR framework into pressure indicators and formed two types of indicators, namely, state and pressure indicators. We set a positive (beneficial to the ecosystem) or negative (unfavorable to the ecosystem) direction for every indicator.

At the beginning of the study, we created the entire indicator system, including 107 indicators such as forest coverage, proportion of natural forest, and proportion of public welfare forest. By taking into account certain principles, including the availability of data and importance and balance of indicators, we initially selected 45 indicators to establish a highly operational evaluation indicator system from the system. The detailed information of indicator system for three major ecosystems is illustrated in Tables 1 and 2. The state indicators include the indicators of basic class, resource class and disaster class. And the pressure indicators include the indicators of general pressure class, behavior class and maintenance class. In the actual project, we need to constantly adjust and improve the system to obtain the final evaluation indicator system. After clarifying the final evaluation indicator system, we determined the data items that needed to be collected according to the indicators in the system.

In this work, we use the forestry ecological security index (FESI) to measure the situation of forestry ecological security (Qiu et al., 2008) and the forestry ecological carrying capacity index (FECCI) to measure the forestry ecological carrying capacity (Kailei et al., 2016). FESI and FECCI are collectively referred to as forestry ecological index, the calculation process of which is shown in Fig. 1. In the calculation of forestry ecological index, data on forestry ecological data items are collected first, and the value of every indicator in the evaluation indicator system is obtained by data calculation. Then, the respective ecological security indexes, including forest ecological security index, wetland ecological security index, and desert ecological security index, for the three major ecosystems are calculated by the corresponding values of indicators combined with the indicator weights, and FESI is calculated

Table 1
Detailed information of pressure indicator system.

Indicator classes	Indicators of forest ecosystem	Indicators of wetland ecosystem	Indicators of desert ecosystem
General pressure class	Population density Energy consumption unit area	Population density Energy consumption unit area	Population density Energy consumption unit area
Behavior class	Sulfur dioxide emission intensity Forest harvesting intensity	Sulfur dioxide emission intensity	Sulfur dioxide emission intensity
Maintenance class	Proportion of nature reserve area (forests and plants) Government forestry investment intensity Annual afforestation ratio	Proportion of nature reserve Government forestry investment intensity	Proportion of nature reserve Government forestry investment intensity