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The role of big data in China's sustainable forest management

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Abstract

Purpose – Forest as a vital natural resource in China plays an irreplaceable important role in safeguarding ecological security and human survival and development. Due to the vast territory, huge population and widespread forest landscape of China, forest management is a complex system involving massive data and various management activities. To effectively implement sustainable forest management, the big data technology has been utilized to analyze China's forestry resources. Thus, the purpose of this paper is to clarify the role of big data technology in China's forest management.
Design/methodology/approach – In this paper, the authors revisited the roles of big data in forest ecosystem monitoring, forestry management system development, and forest policy implementation.
Findings – It demonstrates that big data technology has a great potential in forest ecosystem protection and management, as well as the government's determination for forest ecosystem protection. However, to deepen the application of big data in forest management, several challenges still need to be tackled.
Originality/value – Thus, enhancing modern science and technology to improve big data, cloud computing, and information technologies and their combinations will contribute to tackle the challenges and achieve wisdom of forest management.

Keywords Ecosystem services, Big data, Forest management, Forest fire, Forestry policy, Management system

Paper type Literature review

1. Introduction

Forest is one of the key components of ecosystem, which provide various benefits to humans, including timber products, climate mitigation, biodiversity preservation, etc. (Mori *et al.*, 2017). Although forests are under great pressure due to human activities, especially in tropical forests (Sloan and Sayer, 2015), facing climate change issues and acknowledging the serious problem of forest loss, different countries have made great efforts in forest conservation and afforestation. China initiated a series of reforestation and afforestation

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programs to conserve and expand forests with the goal of mitigating land degradation, air pollution and climate change since the early 1980s (Liu *et al.*, 2008; Zhang *et al.*, 2000). With a dozen years of efforts, China has contributed greatly to the global net gain of tree cover, which alone accounts for 25 percent of the global net increase in leaf area with only 6.6 percent of global vegetated area since 2000 (Chen *et al.*, 2019). It should still be noted that tree cover is not necessarily the forest cover; however, the net gain in the forest cover is the result of a net loss of high-quality forests being outweighed by a net gain in the afforestation in bare lands (Song *et al.*, 2018). Therefore, it is still essential to monitor forest resources for forestry policy making and management.

Forest management is a complex system (ecological, economic and social) that involves massive data and various management activities, including those focused on the ecology of the ecosystem or on the economics of forest businesses (Bettinger *et al.*, 2016). For example, global climate mitigation and adaptation requires effective systems for monitoring forest cover to calculate carbon stock (Bustamante *et al.*, 2016); forestry ecological engineer constructions require evaluation of forest ecosystem services to properly decide payment for environmental services from forests (Sheng *et al.*, 2017); and timber or revenue production in a sustainable manner requires more efficient production processing cycle monitoring (Zelinka *et al.*, 2018). In these cases, better information technologies and more timely inventories on forest resources will result in more reasonable and efficient decision making, such as providing more options for conserving biodiversity, planning and implementing sustainable productive use of resources, including determination of allowable cut and plantation and natural forest management, etc. Here, big data technology is playing a very important role in global forest management. Moreover, emerging big data technology is playing a significant role in forest management at multiple spatiotemporal level. Big data generally refers to massive volumes of data not readily handled by the usual data tools and practices and presents unprecedented opportunities for advancing science and informing resource management through data-intensive approaches, and big data technology is making possible a new kind of environmental activism in the process (Strickland, 2014). When a tree falls in the forest, these days, it does not just make a sound, it causes a computer program to generate an alert that is sent out to activists, researchers, and environmental policymakers around the planet. Forest cover change trends since the year of 2000 and forest loss at a resolution of 30 meters can be examined with a global map. Big data techniques are frequently enough to track deforestation hot spots in places such as Indonesia and Brazil. Forest managers can easily find signs of illegal logging or slash-and-burn agriculture in the tropics. Collectively, researchers are encouraged to join the larger scientific community in global initiatives to address major scientific and societal problems such as forest protection by harnessing big data power (Hampton *et al.*, 2013).

China's forestry resources development has been challenging due to serious problems such as shortage, inferiority and uneven distribution of forestry resources. The vast territory, huge population and widespread forest landscape of China have led to the numerous indexes and complex data (Li, Hao and Chi, 2017; Li, Cui and Liu, 2017); therefore, it is important to improve efficiency and accuracy of forestry resources investigation and forest cover monitoring to ensure the sustainable development of the forestry resource. In this case, the theory and technology that are developed on the basis of big data can be widely applied to analyze China's forestry resources (Li, Hao and Chi, 2017; Li, Cui and Liu, 2017). Thus, the main purpose of this paper is to clarify the role of big data in China's forest management. The second part of this paper discusses the applications of big data to research works on forest ecosystem. The third part explains how big data promotes forest businesses, whereas the fourth part reviews the policies and measures on forest management issued by governments driven by big data technology. The paper ends with conclusions and discussion about the prospects of big data in forest management.

2. Forest ecosystem services analysis and forest fire predication using big data

2.1 Forest ecosystem services analysis

Forest ecosystem is the main body of the terrestrial ecosystem; understanding the spatial and temporal distribution of forest ecosystem services is as vital as their actual value for forest management. The existing problems in China's effective organization and management of forest ecological environment mainly stem from the lack of spatial and temporal data sets and insufficient study of the dynamic changes of forest ecosystem services. Accurate and detailed measures of changing pattern in forestry area have been difficult to obtain in China. In the past, most studies have relied on forest inventory data, which are reported by the State Forestry Administration in every five to six years. Although some land use data are available through the annual statistical year books, the quality of such data has long been questioned. Whereas forest ecosystem service assessment, at present, has entered the period of big data after the period of small data and surface big data (Gijzen, 2013; Hampton *et al.*, 2013), many studies have applied big data, especially remote sensing (RS) data, to measure forest inventory as well as to monitor and manage forests ecosystem at regional levels. With high-resolution RS data, a 1-km area percentage data model (1-km APDM) with RS data are developed and used to monitor forestry area, which examines the conversions of forests, and to identify the spatiotemporal characteristics of land conversions between forests and other land uses/covers and internal conversions between forest cover types (Deng *et al.*, 2010). The 1-km APDM is a feasible and important tool to trace the spatiotemporal patterns of the forest conversions at a finer resolution. Based on the 1-km area percentage data, Deng, Huang, Huang, Rozelle and Gibson (2011), Deng, Huang, Uchida, Rozelle and Gibson (2011) tested whether the existence and the size of roads (ranging from expressways to tertiary roads) affected the level of forest and grasslands cover within 1 km^2 (pixel) units. Furthermore, Deng, Yin, Uchida, and Rozelle (2012) made a great progress in measuring forestry area by providing the first detailed statistics for changes in forestry area for the entire China, based on RS data. Importantly, the RS-based forestry area data are complementary with the official government statistics for future monitoring of forest cover in China.

Apart from forest monitoring based on RS data, forest ecosystem service assessment based on long-term monitoring data from forest ecological stations can obtain more detailed information from the big data, and thus multi-scale evaluation can be carried out. At the same time, the random error brought by selection of small data sample can be avoided to make the evaluation results more reliable. Such long-term monitoring data from forest ecological stations provide support for forest resources protection and sustainable development (Song *et al.*, 2015; Tien, 2013). With the development of big data, it has become feasible to set up a database to monitor the changes of forest ecosystem services and achieve a more accurate visualization in the future (Li, Hao and Chi, 2017; Li, Cui and Liu, 2017). Additionally, the development of field observation technology and the application of advanced observation equipment have led to a rapid increase in the amount of ecosystem observation data, providing a good data foundation for the evaluation of ecosystem services based on big data. Research works have shown that ecosystem services can only be fully expressed by humans on a larger scale such as landscapes and regions (Prager *et al.*, 2012; Tscharntke *et al.*, 2012). In recent years, Chinese forest ecosystem research network has developed rapidly and continuously improved. The long-term monitoring data of forest ecological stations provide data support for the evaluation of forest ecosystem service functions (Niu *et al.*, 2013). Due to the particularity of big data, traditional data processing methods are no longer suitable. Niu *et al.* (2012) carried out a distributed measurement method for forest ecosystem service functions, which decomposes the complex evaluation process into several measurement units, and then the final evaluation result is accumulated step by step. This allows for the integration of big data from forest ecological stations in each assessment unit, avoiding the cumbersome steps of processing big data on a larger scale. Management of ecological performance and forest protection could be improved by utilizing big data to acquire more intelligence or latent knowledge (Xie *et al.*, 2017).

Forest ecosystem service assessment based on long-term observations of forest ecological stations can reveal deeper phenomena, such as analyzing different spatial and temporal patterns of forest types, and leading functions of forest ecosystems in a certain region, and carrying out driving force analysis (Song *et al.*, 2015; Niu and Wang, 2012). These studies can deepen people's environmental awareness, strengthen the dominant position of forestry construction in the national economy, improve the level of forest management, and accelerate the integration of the environment into the national economic accounting system and correctly handle the relationship between social economic development and ecological environmental protection.

2.2 Forest fire prediction

Forest fires are one of the threats to the forest ecosystem and environment; thus, its predication or early detection based on big data will contribute greatly to sustainable forest management. Generally, the forest area or wildland has the high possibility to have forest fires and to have a significant damage to the environment (Ramachandran *et al.*, 2008). According to the statistics of China, from 1952 to 2012, there were 798,500 forest fires and 38,060,000 hectares of forest was destroyed, which caused about $22m loss a year (Niu and Zhai, 2012). There exist complex factors that cause forest fires, among which local weather and human behaviors are the factors that mostly relate to forest fires. Additionally, high incidence and destructiveness of forest fire determine the importance of forest fire prediction or early detection. With the development of big data technology, such as rechargeable wireless sensor networks (RWSNs), forest fire prediction can be implemented and forest fire risk can be calculated. Humans have the ability to obtain the information of forest environment using RWSNs and analyze the complex relationship between the forest fire and the information. The RWSNs collect continuous 24-hour weather information, which can reflect the high accurate status of forest environment. Based on big data integration in study, Dutta *et al.* (2016) found that Australian bush-fire frequency was increasing significantly. The high possibility of potential forest fires risk can be measured by the big data analysis algorithm (Lin *et al.*, 2018); therefore, more attention needs to be paid to prevent forest fire condition.

Forest fire warning is one of the key fields of fire security (Rossi *et al.*, 2011). The overall goal of a big data-based forest fire management system is to improve the visibility of the fire protection system and to narrow the gap between strategy and execution (Bellatreche *et al.*, 2015). As the forest fire has different time and space attributes, it is necessary to consider the combined effects of various factors on forest fire prevention at different time points and different regions (Wang *et al.*, 2017). Video fire alert system based on big data is a fast and effective way for such application, which is also active for the study of early warning (Mahdipour and Dadkhah, 2014). Big data model has the characteristics of security and stability, which can be suitable for more complex application scenarios and can guarantee the stability of the system for a long time (Zhu *et al.*, 2015).

Management of ecological performance and forest protection could be improved by utilizing big data to acquire more intelligence or latent knowledge. On the one hand, forest ecosystem service assessment based on big data can obtain more detailed information and be carried out on a multi-scale. At the same time, it can avoid the random errors caused by the selection of small data samples, making the evaluation results more reliable. On the other hand, forest fire predication or early detection based on big data will contribute greatly to sustainable forest management. The forest fire early warning system based on big data shows its feasibility and effectiveness in practical applications.

3. Forestry resources management system based on big data

Recent advancements in information and big data technologies have led to an increasing development of forest resources management systems, which include forestry production management system, forest information platform and comprehensive forest resources management systems, etc. Forestry industry has the characteristics of long production cycle; once a decision-making error occurs, it is hard to trace back and recover. In this case, a comprehensive production management system supported by information and big data technology, which could accelerate information feedback and help adjust strategies, is needed in realizing forestry protection and sustainable production. In this case, the development of "precision forestry" system has become an innovative solution to increase yield and efficiency of forestry industries while simultaneously reducing the environmental impact, which uses information technologies and analytic tools to guide forestry management strategies (Fardusi *et al.*, 2017). In the system, big data technologies connect data from satellite, airborne, unmanned aerial vehicles, global positioning systems, and many sensors, devices and other geospatial tools, which enables highly repeatable measurements, actions and processes to manage and harvest forest stands, simultaneously allowing information linkages between production and wood supply chain, involving resource managers and environmental community; all these factors are contributing to the wider goal of sustainable forest management (Corona *et al.*, 2017).

China continues to be the world's largest producer, consumer and trader in forest products. It is necessary to build a forestry informatization platform for forestry integrated development. In this case, big data could integrate forestry resources, forestry industry, spatial geography, natural society and other information, promote large-scale production and intensive management of forestry, and vigorously promote the development of modern forestry. In 2016, China Forestry Big Data Center and China Forestry Right Trading (Storage) Center (Abbreviated as "Dual Center") was founded in Yunnan province. The forestry informatization platform depends on rich forestry resources in Yunnan province and aims at constructing a network of forestry information in China, an intelligent and multidimensional visual picture of forestry for ecological construction and industrial development, as well as performing as a dual center. Analyzed results at the platform based on big data technology could be used by forestry administrator, farmers and companies; forestry experts could solve problems for farmers online. In particular, users could complete forestry production, forestry right and other trades online. In general, the informatization platform not only makes forestry trades convenient, but also guides forestry industrial to develop scientifically. Based on informatization platform, forestry resources and industries, natural and social data will be combined deeply for realizing forestry large-scale production and intensive management in the future. Forest management is a complex process that integrates environmental management and also economic development, thus making comprehensive forest resources management a topic of great current interest. The National Forestry and Grassland Administration of China (NFGA) launched a program named Forest Land "One Map," which is a coordinated and integrated mapping program for the whole country involving different ministries and agencies, covering basic geographical factors, land conditions, forest cover factors, planning and management factors, forest economics, and many other topics (Xu *et al.*, 2015). In addition to national-level forest resources management, many provinces and cities have conducted pilot constructions of forest management systems. For instance, Qinghai province promoted the pilot construction of Intelligent Management and Control System in 2013, in which a real-time dynamic monitoring system on forestry was also developed with video surveillance, computer networking and other high-tech means in order to warn forest fires, insect pest and theft early. Similarly, in Henan province, Shanxi province, Chuzhou city and many other cities and provinces have employed forestry resources management system, which could collect, manage, analyze, applicate and update forestry-related data. By constructing a basic geographic information environment in two and three dimensions (3D), massive dynamic 3D data could be seamlessly displayed in exhibition subsystem; many kinds of thematic maps and shared information could be built, as well as forestry resources statistics and tables could be searched. Except for constructions of forest management system to monitoring their current situations, to assisting comprehensive forest management decision making, to analyze scenario prediction with empirical statistical methods is good for making plans of regional forest development. Meanwhile, Deng *et al.* (2008), Deng, Yin, Lin, Jin and Qu (2012) developed the computable general equilibrium models of land use change (CGELUC) and dynamics of land system (DLS) for policy simulation and land spatial modeling, which are useful tools for sustainable land management. The CGELUC is a mechanistic model based on microeconomic theory, and it not only can effectively reflect mechanisms in structural changes in regional land use, but also provide support for forestry resources management strategies. The DLS is a collection of programs that simulates pattern changes in land uses under given land use scenarios by integrating several driving factors of spatial pattern changes, land use conversion rules and dynamic spatiotemporal processes of land use changes. The combination of CGELUC and DLS models can be applied to simulate and predict regional land use change, including forest land under different scenarios (Jin *et al.*, 2017), whereas Luo *et al.* (2014) applied the CGELUC to predict changes of forest resources in the Yunnan province during the period of 2008–2020 under the baseline scenario, a low total factor productivity (TFP) scenario, and a high TFP scenario. Overall, forestry management strategies will depend on the dynamic changes of forest resources, which can be presented clearly through big data technologies and scenario-based modeling.

Generally speaking, forestry resources management system is a useful tool for ensuring quantity, quality, construction and distribution of forest resources. With the help of both information and big data technologies, forest resources monitoring is more scientific and accurate. It is more reasonable for managers to adjust forestry management and production plans and forest cutting quotas.

4. Implementations of forest management policies driven by big data

Facing severe degradation of forest and rapid development of big data, the NFGA has already launched forestry information research and "intelligent forestry" research. Since 2013, the NFGA issued policy-related documents such as "China wisdom forestry development guidance" and "Guidelines on promoting the development of China forestry Internet of things." Especially, the NFGA officially released "Three-year work plan for implementation 'The outline of action program to promote the development of big data'" and "The guidance on accelerating the development of China forestry big data" in 2016. All of these indicate that promoting the application of big data in forest ecosystem protection and forest resources development has become an important content of national forestry management policy.

According to the work plan and guidance on development of China forestry big data, the main task is to build four systems, namely forestry big data acquisition system, application system, open sharing system and technical system. In the meantime, five demonstration projects, including the ecological big data sharing service system, the Beijing–Tianjin–Hebei region forestry data and resources sharing platform, the Belt and Road forestry data and resource collaborative sharing platform, the Yangtze river economic belt forestry data and resource collaborative sharing platform and ecosystem services big data intelligent decision-making platform, will be constructed. In addition, based on construction of the forestry big data, national ecological big data center, national ecological big data research institute and national ecological big data application engineering laboratory will be established. Currently, relying on the forestry data sub-center of national natural resources and geospatial basic information database, the basic environment database management system, 91 forestry databases, relevant standards and management methods have been established. A national satellite RS data application platform for forestry has been established, providing a large number of RS data products for forest resource monitoring, annual update of woodland and wetland monitoring.

Along with the implementation of the plan and guidance, forestry big data has been gradually constructed and applied. For instance, an ecological big data public service platform of "where to go tomorrow" and "fruit is ripe" has been built up, which is providing big data support for the development of forest tourism, fruit industry and other forestry industries. Furthermore, the construction of China forestry network intelligent decision-making system applied big data technology to conduct a comprehensive collection and analysis of users' access data of China forestry site, accurately tracking user needs and hot spot trends. Special reports on ecological big data, such as "analysis report on the Internet repercussions of the reform of state-owned forest farms and state-owned forest regions," "spatial-temporal characteristics of China-ASEAN regional ecological environment" and "distribution and change characteristics of global large international important wetlands" were developed to provide scientific basis for major decision making.

The formulation and implementation of forestry management policies driven by big data, which include accelerating the establishment of forestry big data system, forestry big data demonstration area and forestry big data research institutions as well as promoting big data technology research and application in forestry, demonstrated the great role and potential of big data technology in forest ecosystem protection and management, as well as the government's determination for forest ecosystem protection.

5. Conclusions and discussions

Forest as a vital natural resource in China plays an irreplaceable important role in safeguarding ecological security, human survival and development. In this sense, China has emphasized the importance of sustainable forest management to tackle climate change, improve forest ecosystem services, increase forestry resources management efficiency, etc. At the same time, big data as a new idea and technology has been widely applied in China's forest management, such as forest ecosystem monitoring, forestry management system developing, and forest policy implementing, etc.

By utilizing big data, more intelligent knowledge and information can be integrated to accurately assess the ecological performance of forest and effectively predict forest fire on a multi-scale. Multi-category monitoring and management systems for the forestry industry have been developed on the basis of big data technology and widely piloted at the city, provincial and even national level, which can effectively improve the efficiency of forestry production and management. Additionally, China's recent major forestry planning and management policies, which are driven by big data technology, promote the application of forestry big data in the protection of forest ecosystems and development of forestry resources. The implementations of the polices with the assistance of big data technologies have achieved remarkable results, which include accelerating the construction of forestry big data system, establishing forestry big data demonstration area and forestry big data research institutions as well as promoting forestry big data technology research and application. These results demonstrate the great role and potential of big data technology in forest ecosystem protection and management, as well as the government's determination for forest ecosystem protection.

Big data technology has been recognized as an innovative tool for sustainable forest management; however, there still exist many challenges. China's forestry big data processing is very complex, which needs to establish a complete database to integrate various types of information, such as natural resources and geographical data, forestry policies and regulations, forestry statistical data, and many other thematic data sets. It is urgent to eliminate data islands and to expand and improve data quantity. Besides, big data analytics requires forestry workers to accurately find the available data and extract laws and information from a large amount of data. However, in the process of extraction, dealing with inaccurate data and analyzing data reliability are frequently troubling the forestry workers. Additionally, improving real-time forestry data analysis efficiency is another challenge in big data development. The real-time analysis of forestry data will help the administrator to provide feedback quickly. Only by finding the problems immediately, they can be solved more effectively. With rapid development of modern technologies, combining big data, cloud computing, and information technology can ensure wisdom of forest management, which will be effective to tackle the challenges and to form a modern forest management mode with international leading information base, high quality of ecological management, and optimized forestry industrial structure and innovation ability development.

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