Research progress on monitoring and assessment of forestry area for improving forest management in China

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Abstract

Purpose – The purpose of this paper is to provide the extensive review on dynamic monitoring of forestry area in China.

Design/methodology/approach – Countermeasure and suggestions were proposed for three aspects including the establishment of data sets with unified standards, top-level design of monitoring and assessment and analysis models, and establishment of the decision support platform with multiple scenario simulation.

Findings – Finally, the authors proposed key research area in this field, i.e., improving the systematic and optimal forest management through integrating and improving the data, models and simulation platforms and coupling the data integration system, assessment system and decision support system.

Originality/value – The authors explored the limitation of dynamic monitoring and state of the art research on data accumulation, professional model development and the analytical platform.

Keywords Dynamic monitoring, Forest land management, Forestry area, Forestry area change

Paper type Literature review

1. Introduction

As a key land use type, forest land has important economic value, and also bears important ecological service function, and plays an irreplaceable role in the process of human survival and development. The change of forestland area has great influence on regional climate, biodiversity, homeland ecological security and even global environment change.

Especially, China is in a critical period of urbanization and industrialization, serious ecological environmental problems such as air pollution caused by economic development. Sustainability in China needs to be realized through ecological environment construction, especially effective protection and utilization of forest resources. However, according to the 7th national forest inventory outcome (2009–2013), China's forest area only remains 208m hectares, and the forest coverage is only 21.63 percent, far lower than the world average level of 31 percent. In addition, forest area per capita is only one-fourth of the world average

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level, and forest stock volume per capita is only one-seventh of the world average level. With the development of China's social economy, how to effectively protect, develop and utilize the limited forest resources has become a major problem to be tackled in the ecological environment construction. The most critical basic work is to find out the stock and change of forestland resources efficiently and accurately, and to carry out effective dynamic monitoring of the current forestland area.

On the other hand, China's vast territory, uneven distribution of forest resources, illegal occupation of forest land and deforestation are still prominent problems in current process of economic development (Managi and Kumar, 2018). Acceleration of urbanization and industrialization will further squeeze the ecological construction space, and bring great pressure on strictly defending the forest red line. Therefore, forest management has become an important part of land-use management in China. How to optimize and strengthen the management of forest resources based on the dynamic monitoring of forestry area change has become an extremely important and urgent task in the current land use management and ecological civilization construction in China.

Forests are basic resources to maintain ecological security and achieve regional sustainable development in China. Forestry area changes can result in many ecological problems including soil erosion, water shortages, drought and biodiversity loss (Xie *et al.*, 2016). Moreover, the warming climate has major effects on dynamics of forest land (Solberg *et al.*, 2009). To meet the dynamic monitoring needs database tools to guide forest area monitoring capacity building has been worked out (Gillis *et al.*, 2005). A georeferenced LANDSAT digital database is widely used for dynamic monitoring and it is considered as basic work for monitoring capacity building. Temporal evolution of the NDVI can be as an indicator of forest area changes (Illera *et al.*, 1996). And dynamic monitoring of forest area usually adopts ecological indicators. Therefore, many countries have constructed a comprehensive dynamic monitoring system of forest area to monitor forest utilization changes and (Koop, 2012). With development of modern technologies, these countries have used radar, remote sensing (RS) and geographic information system (GIS) to improve monitoring capacity. In China, many provinces have completed dynamic monitoring technology plan of forest area and built a comprehensive dynamic monitoring system, including databases, management systems, decision support systems and service platform integration. These modern technologies are widely used to improve.

Based on this, the paper provided thorough review on dynamic monitoring of forestry area in China, discussed the technical problems existing in the current dynamic monitoring and impact assessment of forestry area changes, and proposed the countermeasures for dynamic monitoring and optimization management of forestry land changes. In addition, it looks forward to the future priority fields of forest land optimization management and provides decision-making reference for dynamic monitoring and impact assessment of forest land changes in the future.

2. Research progress on monitoring of forestry area

From a global perspective, the dynamic monitoring technology of woodland area is closely related to the development of land use/cover change (LUCC) related technologies (Turner *et al.*, 1995). RS based dynamic monitoring mainly explains the speed and the range of land use change, and the scientific and cultural factors affecting LUCC (Verburg *et al.*, 2009; Biro *et al.*, 2013). In terms of dynamic monitoring of forestry area changes, scientists first adopted aerial photographs to conduct land surveys and system researches in small areas, but it was still far from meeting the reality demand. After the 1950s, people began to explore the feasibility of applying RS data to large-scale land use mapping. Especially since the USA launched the first land observation satellite in 1972, RS technology has been widely used in dynamic monitoring of forestry area changes in China (Xiao *et al.*, 2006), especially suitable for remote areas or those urgently needed data (Roberts *et al.*, 2003; Cingolani *et al.*, 2004; Joshi *et al.*, 2016). Since LUCC is closely related to human activities, ecological environment changes at local, regional and global scales and forestry area changes monitoring is a basic research work (Houghton, 2003; Wu *et al.*, 2003; Pettorelli *et al.*, 2018). LUCC researches based on RS data had been widely carried out on a global scale to monitor environmental changes, including coastlines, watersheds, agriculture, forestry and urban changes (Berlanga-Robles and Ruiz-Luna, 2002; Meneses *et al.*, 2017). Codjoe (2004) used RS data to analyze the effects of human activities on forest vegetation changes. Romero-Ruiz *et al.* (2012) used Landsat and CBERS RS data to monitor and analyze the land use dynamics in Llanos Orientales, Colombia from 1987 to 2007, and analyzed the landscape transfer and its socio-economic drivers. Rojas *et al.* (2013) analyzed the forestry area changes of the Concepción metropolitan area in Chile from 2000 to 2010 in combination with geographical factors and urban planning factors. Tovar *et al.* (2013) analyzed the forestry area changes in the Jalca steppe region of the Peruvian Andes from 1987 to 2007 based on elevation gradient and spatial pattern change. Wasige *et al.* (2013) studied the impact of LUCC changes on agriculture and water quality in Kagera, Lake Victoria. With the RS data and ancillary data, the change of land use types and characteristics in the basin were monitored and analyzed. Using RS techniques, Spera *et al.* (2016) mapped forestry area changes across the Cerrado from 2003 to 2013 and explored the changes in forestry areas and the way of land-cover affecting regional climate feedbacks in the Cerrado.

The dynamic monitoring of the forestry area is mainly reflected in the monitoring of the area and quality change of the forest as is linked with the conversions between forest land and other land types. RS and GIS technologies have been widely used in forestry monitoring studies. Singh *et al.* used the 1972 Landsat MSS and 1986 Landsat TM RS image data to conduct the dynamic monitoring of forestry area in the Ranikhettahsil of India from 1972 to 1986. Siddiqui *et al.* (2004) used satellite RS and GIS technology to analyze the dynamic changes of forestry area in the Sindh of Pakistan from 1977 to 1990–1998. Smith *et al.* (2008) applied RS data to analyze the dynamic changes of Nordic coniferous forests, and combined with dynamic ecosystem models to study the primary net productivity of coniferous forests in the study area. Wulder *et al.* (2010) used a multi-period monitoring framework and MODIS (Moderate-resolution Imaging Spectroradiometer) data to successfully identify 78 percent of the forestry area changes obtained by Landsat RS monitoring, which indicate that verifying that medium-resolution RS images such as MODIS can be combined with other RS images to meet the urgent need for data information in the formulation of relevant policies.

China's special research on the dynamic monitoring of forestry area has developed with the increasing demand for forest resource inventory. RS is a mature method to monitor the dynamics of forestry area. However, with the development of China's social economy, especially the construction of ecological civilization, the main functions of forest land have gradually changed from economic function to ecological function. In this context, the actual demand puts forward higher requirements for forestry monitoring technology. The current research focus has gradually changed to the use of "3S" technology (i.e. RS, GIS and Global Positioning System to monitor the changes of forestry area. Taking for example of Daning County, a key pilot area of the Three North Protection Forest Project in China's Loess Plateau, Qiao *et al.* (2004) explored the method of using RS technology to monitoring the dynamic change information of forest vegetation, which indicated that the method is worth widely popularized, by which the dynamic change information of the forest vegetation can be monitored simply and quickly so as to explore a scientific, rational and effective road for us to rectify the territory of China's Loess Plateau, change the poor physiognomy of the area, improve the ecological environment and promote the development of national economy.

Tan *et al.* (2016) explored the forestry area changes of Zigui County from 2008 to 2014 by using multi-source remotely sensed imagery. Based on 0.5 m resolution Worldview-2 data and 1:10,000 forest stand-wise vector data, Wei *et al.*'s study monitored on forest resource dynamic during 2010–2011 in Pingtan Island. The results indicated that forest in Pingtan Island had changed greatly.

With the development of RS technology and GIS technology, the analysis of forestry area changes become simple and feasible, and the operation costs are decreased in China. Thus, RS and GIS are widely used in forestry area dynamic monitoring in China. In order to satisfy the China's demand of land resources monitoring and clarify the coupling process between human activities and global environmental change as well as the interaction mechanism, a land use database scaling in 1:100,000 was established based on RS and GIS technology by several China's government organizations and scientific research institutions, forestry area changes were included (Li, Lu and Kuang, 2016). Furthermore, land use/cover data have been updating so as to identify the latest macro-situation about forestry area changes in China.

Despite the classification systems is different, the dynamic monitoring forestry area and its related land has developed rapidly since the 1970s in China. Compared with other countries, the research on dynamic monitoring of forestry area in China started from dynamic monitoring of land use. As for the research of large and medium-scale LUCC, it originated from the late 1950s. China's forestry area changes research achieved rapid development by the 1970s. On the one hand, forestry area changes were applied to the assessment of forest resources. On the other hand, the quality of forestry area changes was taken into account to the division of agricultural region as well as agricultural development direction. In addition, mapping of forestry area changes on various scales was carried out simultaneously (Han *et al.*, 2015). Based on the forestry area changes database, domestic scholars have carried out many researches from various perspectives. For instance, temporal and spatial characteristics of LUCC and its driving forces, the impact of LUCC on agro-ecosystems and global changes and the modeling on LUCC in China (Li, Wang, Li and Lei, 2016). Using the land use dynamics model, Liu *et al.* (2010) analyzed the dynamic changes of forestry area in China from 1995 to 2000 and 2000–2005. It revealed the reasons and regulations of China's regional differentiation of forestry area changes.

Those researches on monitoring of forestry area mainly focus on the regulation, characteristics and driving factors of forestry area changes. In the terms of methods, it analyzed from the perspective of geography with RS and GIS. The socio-economic analysis was relatively deficient. Therefore, Deng, Huang, Huang, Rozelle and Gibson (2011) and Deng, Huang, Uchida, Rozelle and Gibson (2011) comprehensively applied spatial econometrics, GIS technology and other interdisciplinary methods to reveal the versatility and heterogeneity of forestry area. It put forward the theory and method of land use equilibrium, deducing the competition curve among farmland, construction land and forest/grassland, which revealed the mechanism and policy implications of land use space conversion (farming land converting to construction land and cultivated land converting to forest /grass land). Through carrying out the empirical research on the China's current prominent non-agriculturalization of land and urban land expansion as well as forest land degradation and grassland shrinkage, it made a significant reference for the optimal management of arable, forest and grassland utilization.

In order to improve the systematic of forest land monitoring research and enhance the decision support ability, based on the multi-source information integrated technology, Deng, Huang, Huang, Rozelle and Gibson (2011) and Deng, Huang, Uchida, Rozelle and Gibson (2011) developed the forest land classification standard. Specially, it divided the forest land type by inversion of forest canopy density according to the color, texture, saturation and spectral characteristic curve of the RS image. The 1 km grid area component data model of forest land, composed by forest land, shrubbery, open forest land and other forest land, was established. It indicated that the mechanism of forest area changes and type transformation. Furthermore, land system dynamics (DLS) model was applied to predict the future trend of forestry area changes in China. Deng, Jiang, Su and Wu (2010) and Deng, Jiang, Zhan He and Lin (2010) used DLS model to simulate land-use conversions between forest area and non-forest cover and the land-use conversions within the sub-classes of forest area for the period 2000–2020 under three different scenarios in Northeast China, which simulate the forest area spatial distribution in any time based on the land use information in the past period. This model leaded to the transformation from data analysis to application research and supporting decision-making. As for the technology research and development and application, Deng, Jiang, Su and Wu's (2010) and Deng, Jiang, Zhan He and Lin's (2010) study had promoted the forest resources survey by RS. The study examined the conversions of forests in Northeast China during 1988–2005 by using a 1 km area percentage data model (1 km APDM) with RS data and to find the spatiotemporal characteristics of land conversions between forests and other land uses/covers and internal conversions between forest cover types. The results satisfied the data and information demand of the national forestry sector for forestry plan making, forest product development as well as forest land resource conservation effectively. RS was applied to test whether the existence and the size of roads affected the level of forestry area or forestry area (Deng, Huang, Huang, Rozelle and Gibson, 2011; Deng, Huang, Uchida, Rozelle and Gibson, 2011) and remote sensing data of the grassland cover in Inner Mongolia was used to test the relation between grassland and construction road (Deng, Huang, Uchida, Rozelle and Gibson, 2011).

Dynamic monitoring techniques provide technical support for impact assessment and improvement management of forestry area changes. Impact assessment is an important means and applied in many fields, including climate change, social economy, environment, management and so on (Assessment, A.C.I., 2004; Glasson and Therivel, 2013; Smith, 2014). Nuissl *et al.* (2009) assessed the impacts of urban land use transitions. Moreover, impact assessment plays an important role in sustainable forestland management. For example, the regional impact assessment underlined the importance of adaptive management strategies to help forest to cope with climatic change (Lasch *et al.*, 2002). Blomley *et al.* (2008) carried out an impact assessment of forest condition. It showed that forest land management has a significance help to improve forest conditions. Luo *et al.* (2014) analyzed forestry area changes in Yunnan Province over the period 2008 to 2020 with the computable general equilibrium model of land use change based on social accounting matrix (SAM) data set under three scenarios. The SAM included land resources, social development and environmental protection accounts, which helped to investigate the competition among different land use types and to optimize the land use structure through maximizing the total land use utility for economic development, social development and environmental protection.

In terms of forest land management, developed countries such as USA has adopted a series of measures to monitor and manage relevant land use activities. In 1905, the USA established the US Forest service under the Ministry of Agriculture. The original intention was to build a multi-functional, long-term natural resource protection fund to ensure its sustainability. The US Forest Service has become an integrated management department now, including land management, education, entertainment, science and technology. It monitors the quality and condition of US forests through daily dynamic monitoring. In developing countries, the United Nations Framework Convention on Climate Change meeting in 2007 adopted the proposal of UN REDD+ (supporting developing countries to implement actions to reduce deforestation, Reduced Emissions from Deforestation and Forest Degradation in Developing Countries), which complements and re-enacts the relevant content of the REDD+ project including sustainable forest management, forest protection, forest carbon stocks and increased forest carbon stocks and environmental problems caused by deforestation and degradation. During the implementation of the project, the dynamic monitoring of forestry area has become one of the basic tasks. Brazil has started the national forest resource inventory since 1980s, while forest resources monitoring system has been gradually established by through RS monitoring and field survey (Tang and Shao, 2015). The monitoring system has played a certain role in promoting the monitoring of forestry area changes.

3. Research progress on impact assessment of forestry area changes

The indicator system should be built to assess impact of forestry area changes. It consists of three parts: natural, social-economic and human indicators. First, climate, topography and soil are the main natural factors influencing forestry area changes due to differences in forest production conditions. Climate includes precipitation and temperature, and the study shows that precipitation, maximum temperature, minimum temperature and temperature difference are related to forest land changes. Moreover, climate changes may cause severe loss in the economic value of forest land changes (Hanewinkel *et al.*, 2013). Slope, altitude and aspect are topographical factors influencing forest land changes. It may further influence forest production. Social economy includes population, total employees and employees in the primary sector, net income of farms per capita, size of the rural labor force, gross domestic product, urbanization rate and secondary sector output value. The economic growth and urbanization rate have major effect on forest land changes. In terms of human indicators, changes on forest land are mainly driven by policy implementation, human activities (deforestation) and residents' pursuit of maximizing economic returns. Some scholars also use landscape indicators to evaluate forest land changes and it can measure size, shape and spatial juxtaposition of forestry area (Dale and Kline, 2013).

The multi-functional type of forestry land management and the rapid changes of forestry area, society and environment requires approaches for assessment, which are supportive to policy and strategy development. Recently, there is an increasing number of methods and approaches to assess, understand and predict the impact of forestry area changes. RS, GISs, and various forms of regression modeling can be used in impact assessment with the analysis of significant amounts of data and information. And modern technology combined with interviews can assess impact accurately. In addition, transfer matrix of land use change is also a good means to describe forestry area changes, and conversion contribution ratios can analyze spatial pattern and quantity characteristics of transfer-in and transfer-out of forestry area. Forestry area changes may bring some bad impact on social economy, ecosystem services and ecological problems. Some scholars use Invest model to assess impact of forest ecological functions caused by forestry area changes. To achieve forest sustainable development, many researches construct a sustainable indicator system to evaluate the effects of forestry area changes. These methods improve efficiency of impact assessment and promote the construction of ecological civilization.

At the first session of the Conference of FAO in the autumn of 1945, the need for up-to-date information on the forest resources of the world was recognized. In May 1946 the Forestry and Forest Products Division was founded and work was initiated on FAO's first worldwide assessment of forests. The sixth session of the FAO Conference in 1951 recommended that the organization maintain a permanent capability to provide information on the state of forest resources worldwide on a continuing basis. Since that time, various other regional and global surveys have been conducted every five to ten years. Many countries have taken actions to access the impact of forestry area changes. For example, forests have long been an essential part of the Finnish national economy representing over 20 percent of its exports in 2013. Finland has adopted legislation to assess the sustainability impacts of forestland changes. Commonwealth and State governments in the major forest regions of Australia has conducted the regional assessment and agreement process through a national forest policy and regional planning (Dargavel, 1998).

In China, the government has implemented a series of specifications, policies and plans to access its impact. Some studies provided a perspective of the interactions between policy changes and socioeconomic factors to assess forestry area changes, which main focus on investigating whether the policy change impacts forestry area changes and how the policy interacts with other socioeconomic factors in affecting these change (Xie *et al.*, 2005). Rozelle *et al.* (2003) made assessment of China's forest sector and figure out the roles that management form and policy have played in forestry area changes. Based on that, the largest challenges for policy makers and draw implications to increase the effectiveness of forest development and protection policy were posed. Hu *et al.* (2008) used Landsat TM/ETM and Quickbird data sets to estimate the forestry area changes and evaluated it through ecosystem services from 1988 to 2006 in the Menglun Township, Xishuangbanna, Southwest China, which indicated that decline of tropical forests would result in a great loss of ecosystem services in this area. Xu and Wilkes (2004) indicated that some change in forestry areas have been due to specific trigger events, the most significant of which reflect national policy changes.

4. Technical challenges on monitoring of forestry area in China

China still faces many defects and shortcomings in technology or capacity building, especially in data accumulation, professional model development and analysis platform construction. Lack of inventory standards has made it difficult to unify forest land information. It is difficult to integrate the forestry area changes information based on the various forest land inventory techniques and different land classification standard. In the process of monitoring implementation, there are serious problems about the uniformity of monitoring standards. For examples, forestry inventory has undergone a process of adjusting the canopy density of forest land from 0.3 to 0.2, but some organizations such as Chinese Academy of Sciences always adopt 0.3 canopy density as the forest land inventory standard, which makes the monitor data difficult to be used in the integrated assessment of forestry area changes and limits the scope of application. At the same time, the forestry area inventory data have been updated slowly, which can't satisfy the needs of integrated real-time monitoring and effective management.

Integrated analysis model combined with dynamic monitoring of forestry area changes needs further development. Some studies have been carried out to study the change characteristics and natural driving forces of forestry area based on geographic analysis method such as RS and GIS technology. Deng, Jiang, Su and Wu (2010) and Deng, Jiang, Zhan He and Lin (2010) using RS to test whether the existence and the size of roads affected the level of forestry area or forestry area changes. From the perspective of economics, some scholars adopted econometrics methods to analyze the forestry area changes based on socio-economic statistical data (Uchida *et al.*, 2007; Deng, 2011). However, these researches are limited in the scope of various disciplines and lack of multidisciplinary intersection. The present condition and changing trend of forestry area combine with the interaction of natural and socio-economic factors. If we can couple the methods of spatial econometrics and GIS and use the disciplinary methods to reveal the quantity and spatial conversion of forestry area, the analysis results can fit better on the basis of natural changes, and provide better decision-making reference information for the optimal management of forest land and other land types.

In some sense, system analysis platform needs to be setup for each nation including China. Systematic analysis of forestry area changes requires comprehensive database and models, and the conversion process from data analysis to application research of the decision-making also needs the support of a system analysis platform. Multi-period and multi-scenario forestry area spatial data products need to be prepared and analyzed by systematic analysis methods. The disclosure of the driving mechanism needs to be extended through the simulation of different policy scenarios in combination with current national forestland planning, forestry product development and forestry resource protection. The development of overall data, model and system involves multi-sectoral, multi-disciplinary technical convergence and requires effective support from the system analysis platform.

5. Implications on forestry monitoring and assessment for improving forest land management

5.1 Implications on forestry area monitoring

A standard unified database needs to be established. The definition and the unification of data standards are the prerequisites for ensuring the dynamic monitoring accuracy and reliability of forestry area changes. It is also the premise for the accurate evaluation of the pre-design and post-production performance of forestry area protection policies. The establishment of large-scale integrated databases is the basis of data analysis. With the development of computer technology and RS technology in forest monitoring, large-scale forest area monitoring data will be utilized in different departments. In this process, unified forestry area definition and its data standards are the most important basic factors. The unified data standard can help to transfer the data obtained by different departments to the database through the internet for sharing, which not only realizes the exchange of data, but also greatly saves the cost of data acquisition. The establishment of the database should be a long-term process. During the construction process, the forestry area monitoring scope can be gradually expanded and the monitoring image resolution will be improved.

The top-down level design monitoring, evaluation and analysis models need to develop. The top-down level concept comes from the concept of engineering. The original meaning refers to the overall consideration of the various levels and elements of the project from a global perspective. Hence, it means that in the model design of forest monitoring, we must fully consider the natural, ecological, socio-economic, political and other factors, and integrate the models into a system. Based on the reality, the model must be established to fit the actual situation and ultimately applied to practice, which truly plays an important role in model evaluation and analysis.

There are urgent needs to construct a simulation platform with multiple scenarios for multiple decision-making support. With the support of forestry area changes dynamic information database, expanding the knowledge base and building a simulation platform with multi-scenarios is one of the most important means to optimize forest land management. Based on the forestry dynamic monitoring database, we can integrate forest land use data, hydrological data, meteorological data and socio-economic data and couple the integrated natural process and socio-economic driven models to meet different requirements including resource utilization, ecological protection, economic development, social development, etc.). And the final decision support system will be used to evaluate the dynamic changes of the entire forestry area, so as to provide a scientific and rational reference to develop forest.

5.2 Implications on impact assessment of forestry area changes

Criteria and questions should be considered in the context of assessing forestry area changes for the purpose of addressing forest policy issues. For example, Chinese government has implemented technical specifications for assessing forestry area changes and made policies to assess climate change effects on forests. It will provide theoretical basis for impact assessment and have an important significance on forest land management. Furthermore, it can promote construction of ecological civilization and achieve sustainable forest land development.

An impact assessment platform needs to be constructed. This platform integrates various assessment methods with amounts of data and information. Those methods include RS, GISs, regression models and invest model. It can not only serve the impact assessment of forestry area changes, but also provide support for decision makers through scenario simulation. Furthermore, this platform can help reflect better the current situation and trends of forestry area changes and assess the impact in different scenarios.

Impact assessment report of forestry area changes should be conducted every five to ten years. Chinese government can organize research institutions in different fields to complete the report. They can integrate various data to analyze forestry area changes and use modern methods to access its impact. This report can reflect the trends of forestry area changes and help decision makers to implement policies to cope with these changes. Moreover, it can help perfect criteria and questions of impact assessment and update platform information timely.

5.3 Implications on the improvement of forestry area management

The forest resources data need to be integrated, clearly defined and classified. Taking the change of forest canopy closure standard in China as an example, the planning to change forest canopy closure will lead to difficulties in the interaction between different data. Re-integrating, classifying and preparing standardized big data of forest resources is one of the core tasks that meet the requirements of national forestry big data.

It is important to enhance the prediction and dynamic analysis capabilities of forestry area changes, frame development paths and recognize regional development goals. Perfecting data integration – model analysis – policy simulation integrated construction and carrying out scenario prediction of forest land change under different schemes are the basic project to improve the analysis of forest dynamic change. And it is also an important premise to understand the trend of forestry area changes, frame the development path and recognize the development goals.

It is essential to identify restrictive factors affecting the development of forestry areas, explore adaptive management means for forestry development, and promote transformation and development strategies based on different stages. Identifying the key contradictions in the process of forestry development and the key factors restricting the development, and implementing adaptive management are the important preconditions under the current climate change, urbanization development, industrial structure transformation, ecological environment protection and so on. In addition, it’s also a necessary measure to promote the transformational development of forestry areas.

6. Conclusions and discussion

The monitoring and assessment of dynamics of forestry area have always been a crucial topic in the literature of forestry. To utilize forest and related resources in a sustainable manner, an optimized managing methodology is needed through analyzing supplies and demand, which has positive significance for forest protection and sustainable development of forest resources.

The goal of forest land management is to achieve a comprehensive development of the social economy under the ecological construction. In future, based on the simulation of ecological risks under different scenarios, policies and suggestions on the protection of forestry area and rational utilization can be applied to improve ecological functions and to promote the coordinated development of social economy. In the process of forest protection and utilization, under the constraints of ecological environmental protection and social and economic development policies, the optimal allocation and design of forest utilization related to this content needs to be carried out to realize the dual objectives of ecosystem service function protection and social economic development.

To achieve optimal forest land management, the improvement and support of data, models and system platforms are required. In terms of data accumulation, the integration of relevant basic data in various regions and departments can be achieved through unified data collection and processing standards. And multi-source data including RS data, survey data and statistical data can be integrated to achieve effectively optimal allocation of forestry area. For model development, the relationship between the ecosystem service system and socio-economic development can be determined with simultaneous equations through a multi-level econometric model. In the platform construction, it can evaluate the comprehensive effects of multi-policy objectives with the simulation of multiple policy schemes in the context of socio-economic development, select and improve the optimal plan for the protection and utilization of forestry area. Finally, it determines the policy suggestions and measures to promote social and economic development.

In the specific implementation, a relatively complete conceptual framework of dynamic monitoring and optimization management platform could be established for forestry area, data integration system (DIS), assessment system (AS) and decision support system (DSS). First, DIS platform integrates multi-source data such as RS, ecosystem research network, and environmental monitoring to form a data set. On this basis, it establishes an AS consisting of information transformation models at different scales and multi-scale problem models, which is used for forest resources diagnosis, assessment and future development scenario analysis. Finally, it generates a response plan and feedback the implementation of the plan to the information input by constructing a DSS, receiving the analysis result information of the AS, and existing policy and measures assessment, policy optimization suggestions and environmental emergency response strategies. With continuous feedback and adjustment, response plan could be optimized.

Based on "National Resources and Environment Remote Sensing Information Platform," the above system can realize the dynamic monitoring and evaluation of forestry area changes at regular intervals (such as every five years). It reveals the spatial and temporal characteristics, the causes and the effects of the dynamics of forestry area, and is conducive to timely discover the prominent problems and main contradictions in the utilization of forest land in China. By improving the understanding of China's macroeconomic, ecological environmental and policy factors and the response mechanism among them, it provides scientific decision-making for the protection of forestry area and the optimal utilization forest land at both regional and national extents.

References

Assessment, A.C.I. (2004), "Impacts of a warming Arctic-Arctic climate impact assessment", in Arctic Climate Impact Assessment (Ed.), *Impacts of a Warming Arctic-Arctic Climate Impact Assessment*, Cambridge University Press, Cambridge, p. 144, December, ISBN 0521617782.

Berlanga-Robles, C.A. and Ruiz-Luna, A. (2002), "Land use mapping and change detection in the coastal zone of northwest Mexico using remote sensing techniques", *Journal of Coastal Research*, Vol. 18 No. 3, pp. 514-522.

Biro, K., Pradhan, B., Buchroithner, M. and Makeschin, F. (2013), "Land use/land cover change analysis and its impact on soil properties in the northern part of Gadarif region, Sudan", *Land Degradation & Development*, Vol. 24 No. 1, pp. 90-102.

Blomley, T., Pfliegner, K., Isango, J., Zahabu, E., Ahrends, A. and Burgess, N. (2008), "Seeing the wood for the trees: an assessment of the impact of participatory forest management on forest condition in Tanzania", *Oryx*, Vol. 42 No. 3, pp. 380-391.

Cingolani, A.M., Renison, D., Zak, M.R. and Cabido, M.R. (2004), "Mapping vegetation in a heterogeneous mountain rangeland using Landsat data: an alternative method to define and classify land-cover units", *Remote Sensing of Environment*, Vol. 92 No. 1, pp. 84-97.

Codjoe, S.N.A. (2004), *Population and Land Use, Cover Dynamics in the Volta River Basin of Ghana: 1960-2010*, Cuvillier Verlag.

Dale, V.H. and Kline, K.L. (2013), "Issues in using landscape indicators to assess land changes", *Ecological Indicators*, Vol. 28, May, pp. 91-99.

Dargavel, J. (1998), "Politics, policy and process in the forests", *Australian Journal of Environmental Management*, Vol. 5 No. 1, pp. 25-30.

Deng, X. (2011), *Modeling the Dynamics and Consequences of Land System Change*, Springer.

Deng, X., Huang, J., Huang, Q., Rozelle, S. and Gibson, J. (2011), "Do roads lead to grassland degradation or restoration? A case study in Inner Mongolia, China", *Environment & Development Economics*, Vol. 16 No. 6, pp. 751-773.

Deng, X., Huang, J., Uchida, E., Rozelle, S. and Gibson, J. (2011), "Pressure cookers or pressure valves: do roads lead to deforestation in China?", *Journal of Environmental Economics and Management*, Vol. 61 No. 1, pp. 79-94.

Deng, X., Jiang, Q.O., Su, H. and Wu, F. (2010), "Trace forest conversions in Northeast China with a 1-km area percentage data model", *Journal of Applied Remote Sensing*, Vol. 4 No. 1.

Deng, X., Jiang, Q.O., Zhan, J., He, S. and Lin, Y. (2010), "Simulation on the dynamics of forest area changes in Northeast China", *Journal of Geographical Sciences*, Vol. 20 No. 4, pp. 495-509.

Gillis, M., Omule, A. and Brierley, T. (2005), "Monitoring Canada's forests: the national forest inventory", *The Forestry Chronicle*, Vol. 81 No. 2, pp. 214-221.

Glasson, J. and Therivel, R. (2013), *Introduction to Environmental Impact Assessment*, Routledge.

Han, H., Yang, C. and Song, J. (2015), "Scenario simulation and the prediction of land use and land cover change in Beijing, China", *Sustainability*, Vol. 7 No. 4, pp. 4260-4279.

Hanewinkel, M., Cullmann, D.A., Schelhaas, M.-J., Nabuurs, G.-J. and Zimmermann, N.E. (2013), "Climate change may cause severe loss in the economic value of European forest land", *Nature Climate Change*, Vol. 3 No. 3, pp. 203-207.

Houghton, R.A. (2003), "Revised estimates of the annual net flux of carbon to the atmosphere from changes in land use and land management 1850–2000", *Tellus B*, Vol. 55 No. 2, pp. 378-390.

Hu, H., Liu, W. and Min, C. (2008), "Impact of land use and land cover changes on ecosystem services in Menglun, Xishuangbanna, Southwest China", *Environmental Monitoring & Assessment*, Vol. 146 Nos 1-3, pp. 147-156.

Illera, P., Fernandez, A. and Delgado, J. (1996), "Temporal evolution of the NDVI as an indicator of forest fire danger", *International Journal of Remote Sensing*, Vol. 17 No. 6, pp. 1093-1105.

Joshi, N., Baumann, M., Ehammer, A., Fensholt, R., Grogan, K., Hostert, P., Jepsen, M., Kuemmerle, T., Meyfroidt, P. and Mitchard, E. (2016), "A review of the application of optical and radar remote sensing data fusion to land use mapping and monitoring", *Remote Sensing*, Vol. 8 No. 1, p. 70.

Koop, H. (2012), *Forest Dynamics: SILVI-STAR: A Comprehensive Monitoring System*, Springer Science & Business Media.

Lasch, P., Lindner, M., Erhard, M., Suckow, F. and Wenzel, A. (2002), "Regional impact assessment on forest structure and functions under climate change – the Brandenburg case study", *Forest Ecology and Management*, Vol. 162 No. 1, pp. 73-86.

Li, L., Lu, D. and Kuang, W. (2016), "Examining urban impervious surface distribution and its dynamic change in Hangzhou metropolis", *Remote Sensing*, Vol. 8 No. 3, p. 265.

Li, X., Wang, Y., Li, J. and Lei, B. (2016), "Physical and socioeconomic driving forces of land-use and land-cover changes: a case study of Wuhan City, China", *Discrete Dynamics in Nature and Society*, Vol. 2016, 11pp.

Liu, J., Zhang, Z., Xu, X., Kuang, W., Zhou, W., Zhang, S., Li, R., Yan, C., Yu, D. and Wu, S. (2010), "Spatial patterns and driving forces of land use change in China during the early 21st century", *Journal of Geographical Sciences*, Vol. 20 No. 4, pp. 483-494.

Luo, J., Zhan, J., Lin, Y. and Zhao, C. (2014), "An equilibrium analysis of the land use structure in the Yunnan Province, China", *Frontiers of earth science*, Vol. 8 No. 3, pp. 393-404.

Managi, S. and Kumar, P. (2018), *Inclusive Wealth Report 2018: Measuring Progress Towards Sustainability*, Routledge.

Meneses, B., Reis, E., Pereira, S., Vale, M. and Reis, R. (2017), "Understanding driving forces and implications associated with the land use and land cover changes in Portugal", *Sustainability*, Vol. 9 No. 3, p. 351.

Nuissl, H., Haase, D., Lanzendorf, M. and Wittmer, H. (2009), "Environmental impact assessment of urban land use transitions – a context-sensitive approach", *Land use Policy*, Vol. 26 No. 2, pp. 414-424.

Pettorelli, N., Schulte to Bühne, H., Tulloch, A., Dubois, G., Macinnis-Ng, C., Queirós, A.M., Keith, D.A., Wegmann, M., Schrodt, F. and Stellmes, M. (2018), "Satellite remote sensing of ecosystem functions: opportunities, challenges and way forward", *Remote Sensing in Ecology and Conservation*, Vol. 4 No. 2, pp. 71-93.

Qiao, Y., Wang, Y. and Tang, J. (2004), "Study of remote sensing monitoring of dynamic change of the Loess Plateau forest resources", *Advances in Space Research*, Vol. 33 No. 3, pp. 302-306.

Roberts, D.A., Keller, M. and Soares, J.V. (2003), "Studies of land-cover, land-use, and biophysical properties of vegetation in the large scale biosphere atmosphere experiment in Amazônia", *Remote Sensing of Environment*, Vol. 87 No. 4, pp. 377-388.

Rojas, C., Pino, J., Basnou, C. and Vivanco, M. (2013), "Assessing land-use and-cover changes in relation to geographic factors and urban planning in the metropolitan area of Concepción (Chile). Implications for biodiversity conservation", *Applied Geography*, Vol. 39, pp. 93-103.

Romero-Ruiz, M., Flantua, S., Tansey, K. and Berrio, J. (2012), "Landscape transformations in savannas of northern South America: land use/cover changes since 1987 in the Llanos Orientales of Colombia", *Applied Geography*, Vol. 32 No. 2, pp. 766-776.

Rozelle, S., Huang, J. and Benziger, V. (2003), "Forest exploitation and protection in reform China: assessing the impact of policy, tenure, and economic growth", Working Papers No. 225890, University of California, Department of Agricultural and Resource Economics, Davis.

Siddiqui, M., Jamil, Z. and Afsar, J. (2004), "Monitoring changes in riverine forests of Sindh-Pakistan using remote sensing and GIS techniques", *Advances in Space Research*, Vol. 33 No. 3, pp. 333-337.

Smith, B., Knorr, W., Widlowski, J.-L., Pinty, B. and Gobron, N. (2008), "Combining remote sensing data with process modelling to monitor boreal conifer forest carbon balances", *Forest Ecology and Management*, Vol. 255 No. 12, pp. 3985-3994.

Smith, L.G. (2014), *Impact Assessment and Sustainable Resource Management*, Routledge.

Solberg, S., Dobbertin, M., Reinds, G.J., Lange, H., Andreassen, K., Fernandez, P.G., Hildingsson, A. and de Vries, W. (2009), "Analyses of the impact of changes in atmospheric deposition and climate on forest growth in European monitoring plots: a stand growth approach", *Forest Ecology and Management*, Vol. 258 No. 8, pp. 1735-1750.

Spera, S.A., Galford, G.L., Coe, M.T., Macedo, M.N. and Mustard, J.F. (2016), "Land-use change affects water recycling in Brazil's last agricultural frontier", *Global Change Biology*, Vol. 22 No. 10, pp. 3405-3413.

Tan, Y., Bai, B. and Mohammad, M.S. (2016), "Time series remote sensing based dynamic monitoring of land use and land cover change", 2016 4th International Workshop on Earth Observation and Remote Sensing Applications (EORSA), IEEE.

Tang, L. and Shao, G. (2015), "Drone remote sensing for forestry research and practices", *Journal of Forestry Research*, Vol. 26 No. 4, pp. 791-797.

Tovar, C., Seijmonsbergen, A.C. and Duivenvoorden, J.F. (2013), "Monitoring land use and land cover change in mountain regions: an example in the Jalca grasslands of the Peruvian Andes", *Landscape and Urban Planning*, Vol. 112, pp. 40-49.

Turner, B.L., Skole, D., Sanderson, S., Fischer, G., Fresco, L. and Leemans, R. (1995), "Land-use and land-cover change: science/research plan", Report No. 35, Unknown Host Publication Title, International Geosphere-Biosphere Programme, Stockholm.

Uchida, E., Xu, J., Xu, Z. and Rozelle, S. (2007), "Are the poor benefiting from China's land conservation program?", *Environment and Development Economics*, Vol. 12 No. 4, pp. 593-620.

Verburg, P.H., Van De Steeg, J., Veldkamp, A. and Willemen, L. (2009), "From land cover change to land function dynamics: a major challenge to improve land characterization", *Journal of Environmental Management*, Vol. 90 No. 3, pp. 1327-1335.

Wasige, J.E., Groen, T.A., Smaling, E. and Jetten, V. (2013), "Monitoring basin-scale land cover changes in Kagera Basin of Lake Victoria using ancillary data and remote sensing", *International Journal of Applied Earth Observation and Geoinformation*, Vol. 21, pp. 32-42.

Wu, J., Jenerette, G.D. and David, J.L. (2003), "Linking land-use change with ecosystem processes: a hierarchical patch dynamic model", *Integrated Land use and Environmental Models*, Springer, pp. 99-119.

Wulder, M.A., White, J.C., Gillis, M.D., Walsworth, N., Hansen, M.C. and Potapov, P. (2010), "Multiscale satellite and spatial information and analysis framework in support of a large-area forest monitoring and inventory update", *Environmental Monitoring and Assessment*, Vol. 170 Nos 1-4, pp. 417-433.

Xu, J. and Wilkes, A. (2004), "Biodiversity impact analysis in northwest Yunnan, southwest China", *Biodiversity & Conservation*, Vol. 13 No. 5, pp. 959-983.

Xiao, J., Shen, Y., Ge, J., Tateishi, R., Tang, C., Liang, Y. and Huang, Z. (2006), "Evaluating urban expansion and land use change in Shijiazhuang, China, by using GIS and remote sensing", *Landscape and Urban Planning*, Vol. 75 Nos 1-2, pp. 69-80.

Xie, X., Xie, H. and Fan, Y. (2016), "Spatiotemporal patterns and drivers of forest change from 1985–2000 in the Beijing-Tianjin-Hebei region of China", *Journal of Resources and Ecology*, Vol. 7 No. 4, pp. 301-309.

Xie, Y., Yu, M., Tian, G. and Xing, X. (2005), "Socio-economic driving forces of arable land conversion: a case study of Wuxian City, China", *Global Environmental Change*, Vol. 15 No. 3, pp. 238-252.

Further reading

Daily, G.C., Zhiyun, O., Hua, Z., Shuzhuo, L., Yukuan, W., Feldman, M., Kareiva, P., Polasky, S. and Ruckelshaus, M. (2013), "Securing natural capital and human well-being: Innovation and impact in China", *Shengtai Xuebao/Acta Ecologica Sinica*, Vol. 33 No. 3, pp. 677-685.

Huang, W., Wang, X., Chen, Y., Zhou, X. and Xiao, N. (2014), "Large-scale forest resource dynamic monitoring using worldview-2 data – a case study in Pingtan Island, Fujian Province, China", *IOP Conference Series: Earth and Environmental Science, IOP Publishing*.

Liping, C., Yujun, S. and Saeed, S. (2018), "Monitoring and predicting land use and land cover changes using remote sensing and GIS techniques – a case study of a hilly area, Jiangle, China", *PloS one*, Vol. 13 No. 7.

Liu, J., Liu, M., Tian, H., Zhuang, D., Zhang, Z., Zhang, W., Tang, X. and Deng, X. (2005), "Spatial and temporal patterns of China's cropland during 1990–2000: an analysis based on Landsat TM data", *Remote sensing of Environment*, Vol. 98 No. 4, pp. 442-456.

Xiang-zheng, D., Jin-yan, Z., Ji-yuan, L. and Da-fang, Z. (2002), "The global rainforest mapping project JERS-1: a paradigm of international collaboration for monitoring land cover change", *Journal of Geographical Sciences*, Vol. 12 No. 1, pp. 15-22.

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