Precise technologies in forestry: problems and prospects

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Abstract. The paper highlights features of transition from traditional to precision forestry. The transition results are: selective cultivation and cloning of seedlings; specific fertilizer treatment; digital forest inventory; fully mechanized logging of trees; early fire detection. It has been established that the high-precision forestry system includes such technologies that involve improvement of the forest management system, providing tighter operations control and improved data collection; increasing recipes selectivity in accordance with a geographical location; automation of operations, from work in nurseries to forest logistics; Search for optimal solutions using geolocation databases and advanced analytics. According to the McKinsey & Company Research Center, the following promising areas for the development of precision forestry have been: genetics and nurseries; forest management (forestry); logging; wood delivery; value chain. Information and monitoring systems for the forest complex are an important tool in developing an effective forest management policy, and most of the tools and technologies used in forestry are somehow related to remote sensing, GIS technologies and global positioning systems (GPS). The information presented is the basis for intersectoral relations strengthening and can reduce costs of deforestation and illegal logging, forest management and forest fires costs as well as forests mapping costs.

1. Introduction

Digital technologies are a progress vector in many spheres of the economy and forestry is no exception. In the use of digital technologies, forestry lags significantly behind other spheres of the economy. The prospect of using digital technologies in forestry is proved by productivity from 5 to 25% increase in total production volume per year in countries where these technologies are actively used, and a quick return on investment.

The conservatism of the forest management system, formed by Hans Carl von Carlowitz [1] more than 300 years ago, is a significant obstacle to its full development and modernization. The existing forest management system creates a number of barriers and difficulties that should be overcome when implementing digital technologies. Implementation of digital technologies in the forest management system is facing legal, technical, personnel and technological problems:

• public-private partnership on forest management in forestry is insufficient;

• the state and tenants of forestry follow the conservative management style, at the same time private entrepreneurs need to balance various commercial goals with social and environmental goals;

• many forest users lack experience in implementing and using accurate forestry technologies (due to the large scale and inaccessibility of forest land);

• despite the fact that there is a wide range of technologies for precision forestry, there are relatively few practical examples that would simplify the understanding of how these technologies are used in real activities.

Despite the serious problems that forestry is facing, there are still examples of successful practices in introducing precision forestry technologies.

The aim of this paper is to analyze the existing effective practices of precision forestry technologies implementation and to consider the possibility of their transfer to Russian forestry.

2. Methods and materials

The methodological basis of the article was the scientific works of domestic [1-4] and foreign [5-11] scientists on application of precision forestry technologies. The research information base is made up of official reports of the Federal Statistic Service of the Russian Federation, the Ministry of Natural Resources and Environment of the Russian Federation, the Federal Agency for Forestry, reports of international organizations, periodicals and Internet resources, as well as the results of our own generalizations and studies.

The systemic and integrated approaches have been used in the work, as well as methods of synthesis and generalization of modern concepts of sustainable management, comparison of foreign and domestic experience of economic relations in forestry, methods of statistical and structural-logical analysis.

3. Results and Discussion

Taking into account the sustainability development level of the institutional subsystem of the Russian Federation and the economic and legal problems of forestry development, the need for new highly efficient technologies is very high [1]. The concept of high-precision forestry, due to intersectoral convergence, is borrowed from agriculture. According to E Lopatin, D Dobrynin, D Baranov, E Tarasenko and I Novoselov high-precision forestry includes planning and conducting forestry activity that is aimed at efficiency improving of wood growing and logging, reducing the forestry costs, as well as maintaining the sustainability of forest ecosystems and preserving biodiversity [2]. Being a technology, high-precision forestry's characteristics allow promote progress from making general decisions to informed decisions based on the most accurate and relevant information on forest resources to achieve forest management goals. Taking into account high level of ecological and social significance of forests, the effectiveness of their use and potential for improved management is significant. The works by E Lopatin, D Dobrynin, D Baranov, E Tarasenko and I Novoselov [2], V N Petrov, T E Katkova and Ms S Karvinen [3, 4] are devoted both to a comparative analysis and trends in the forestry economy development, and to dynamics of economic results of managerial activity of forestry authorities in Russia and Finland. They believe that cooperation between the two countries allows not only to adopt effective work experience, to establish friendly relations and technology transfer, but also to provide conditions for the joint use of digital technologies in cross-border territories, being a guarantee of good neighborly and partnership relations.

In their research, a number of organizations, such as McKinsey & Company [5] and others, came to the conclusion that accurate forestry is not just the introduction of digital technologies for forest management entities, but it is also a paradigm shift: from a fully manual and analog system with extensive management instructions to the system with digital data collection and scheduling, a detailed prescription for management and strict operational control. Features of the transition from traditional forestry to high-precision is the transition:

• from natural forest restoration to selectively grown and cloned seedlings under strictly controlled conditions;

• from the use of standard fertilizers to specialized processing, taking into account the deficiency of nutrients;

• from manual forest inventory to digital using unmanned aerial vehicles;

- from a motor-manual intuitive saw cut of trees to a mechanized saw cut integrated into a common supply system;
- from extinguishing fires after a fire to an early detection and operational response system.

The presented system of accurate forestry includes technologies that offer improvement of the forest management system in several ways and allow:

- detect fires or flood risks;
- scan burned areas for damage;
- use other technologies, such as Light Detection and Range Finding (LiDAr) technology or multispectral cameras;
- disperse seeds and apply herbicides and pesticides.

Precise forestry takes advantage of the understanding of environmental processes in forests that has been accumulated over the past decade. Instead of following a single plan for the entire field, accurate data and advanced analytics can optimize and fine-tune management decisions to suit site conditions such as soil type and fertility, slope, etc. This can provide:

- selection and planting of plant species based on the characteristics of the site, improving the survival of seedlings;
- the use of nutritional supplements or herbicides and pesticides with a variable speed, based on the needs of a particular site and guided by GPS;
- timely monitoring of tree health;
- site automation to combat the shortage of skilled labor;
- forest assessment and timber tracking during transportation;
- a combination of spatial data on tree growth, yield and environmental conditions with the creation of growth and yield models for future management.

According to the McKinsey & Company research center, its organizations have established a set of precise forest technologies or directions that can demonstrate the greatest prospects for transforming operations and improving forest management results (table 1).

Table 1. Promising directions and effective practices of precision forestry [5].

Direction	Description
Genetics and nurseries	– marker-based selection for the plants to have genetic profiles suitable for the site and end use; – automated nurseries (completely closed and controlled conditions for growing seedlings in optimal conditions for plant growth)
Forest management (forestry)	– planting management (techniques adapted to the territory conditions, collection of information on installed soil sensors); – fire monitoring (digital fire monitoring using a UAV or satellite, to ensure the prevention and coordination of fire fighting); – monitoring the state of the forest (digital monitoring of potential disease outbreaks and coordinated measures to minimize damage to plantings caused by pests); – water management systems (centralized control of water infrastructure based on soil moisture, water level in canals, etc.)
Billeting in forestry	– digital inventory (measurement, forest stands inventory – i.e. volume, species and varietal composition; using air, remote sensing); – mechanized procurement (fully mechanized systems to increase safety, productivity and coordination process)

Direction	Description
Wood delivery	– remote / automatic loading (loading cranes controlled remotely); – forest logistics optimization (using modern software for transport logistics management)
Value chain	– forest planning models (software to support decision-making on forest management from strategic to tactical and operational planning); – electronic dashboards (used to visualize data based on one central, standardized data warehouse); – field support tools (mobile devices deployed in the forest that provide managers with access to forest information systems and planning tools); – advanced analytics (data analysis systems to solve complex problems such as limiting tree growth at micro level and determining effective neutralization measures)

It should be noted that the presented directions are focused on the results of activities at all stages of the value chain - from plant genetics, automation of nurseries to the supply of wood to sawmills, pulp mills, etc.

Digital technologies are considered to be a new direction in the activities of any enterprise, although their creation has a long history. Information technologies used to be aimed at solving local problems and obtaining a point result, then multicriteria problems were solved at the organization level, now complex problems are solved at the industry level. Despite the fact that digital technologies are considered relatively new, they have tremendous potential for revitalizing and even radically changing the forest management system at all its levels. There are companies such as CID.Inc that have been working for decades to create accurate plant research tools. Forestry information and monitoring systems are an important tool in developing effective forestry management policy. Information systems play a crucial role in assessing forest resources, investing and ensuring control. The accumulated information on forest resources, which is systematized and analyzed in relevant information systems, helps to ensure effective forest management, justification and management decisions.

Over forty years ago H Mintzberg and others [6] proposed a common model for decision making. The Mintzberg model is still widely used as a general description of the many alternative processes and ways that people and organizations use to move from problem recognition to problem solving. According to the proposed Mintzberg model, any software system that has been designed to implement one or more components of a general process can be described as a decision support system (DSS).

In his work C W Holsapple [7], based on H. Mintzberg's and others [6] research represents DSS as a computer system consisting of a language system, a presentation system, a knowledge system and a task processing system, the main purpose of which is decision support. Despite its wide distribution many decision support systems focus exclusively on the alternative choice phase, which significantly limits the possibility of their large-scale application. Systems that meet the definitions by Mintzberg [6] and Holsapple [7] usually focus on the alternative choice process, include optimization systems as well as expert systems that provide the basis for applying procedural or reasoned knowledge in solving problems. Complex systems such as neural networks, Bayesian networks and systems for solving multicriteria problems, for example, the hierarchy analysis method, use similar or comparable tools. The DSS approaches description is presented in table 2.

Table 2. Evolution of approaches to information systems' formation in forestry.

Approach	Essence of approach
Optimization	Earliest DSS form. Forest Planning (FORPLAN) is the primary analytical system used in strategic planning of national forests in the United States during the 1980s and early 1990s (Iverson and Alston). The main goal of any FORPLAN model is to optimize resource allocation and management planning over a certain period of time, taking into account clearly defined management goals and constraints [6].
Math programming	Solutions of such systems, based on the black box, create difficulties for resource management agencies. In particular, they have an inherent difficulty in explaining the conclusions of decisions. However, mathematical programming remains a popular and viable approach in supporting decision-making for strategic planning.
Expert systems	Those that are similar to human thinking, based on concepts and principles of artificial intelligence (Jackson [8]). Typical applications for expert systems include diagnostics, classification, and forecasting. They turned into a class of DSS technologies for solving problems that are not for conventional computing solutions, for instance, optimization, modeling, and statistical methods. The main components of such systems are a set of facts and rules (knowledge base), an output mechanism that interprets and plans the rules execution, and one or more interfaces for applications development and execution .
Network models	Network theory has created several successful approaches for presenting knowledge on problem solving as a means of supporting decision making. Three of the most successful currently widely used include artificial neural networks (ANNs), Bayesian networks, and logical networks. These network systems are based on artificial intelligence and like expert systems they are well suited for such applications as diagnostics, classification and forecasting, although each of them has its own characteristics.
Multicriteria methods	These methods were originally developed to meet the needs of production and business operations, where inputs, results, resources, participants, flows, and other problematic components can be described with complete certainty. Gradually, these operations research methods were applied for planning in the field of forest and natural resources management - primarily, logging, transportation and processing of wood due to their similarity with production operations.
Integrated Forest Management Systems	Under the influence of ecosystem management, adaptive management, and sustainable forestry in the 1990s, a new class of systems appeared. Rausche [9], characterizes these new technologies as a "full services", system, i.e. the systems combine several functions that are collectively designed to solve larger, more complex and abstract tasks that require support in making decisions. In his work, Reynolds [10] provides an overview of three systems that have gained significant recognition and widespread use: landscape management systems (LMS, NED) and ecosystem management decision support system (EMDS).

Most of the tools and technologies used in forestry are somehow related to remote sensing, GIS technologies and global positioning systems [6, 7, 11]. These technologies are successfully used in European countries (Finland, Austria, Switzerland, Italy, Germany, etc.), the USA, South American countries, less common in Russia and countries Commonwealth of Independent States, Asia, Australia

and Africa. So, for example, remote sensing that uses satellite imagery relies on spectral imagery; unmanned aerial vehicles are used to scan forest land without GPS navigation or automated operations; LiDAr is a remote sensing method that uses a near infrared laser and GPS to accurately 3D-map the earth and forests; detection of land and underground diseases; Canopy Imagers are used to monitor tree growth and health, as well as soil erosion and carbon fixation, etc.

The analysis of using digital technologies in forestry shows that the technologies development for obtaining and processing data allows for the transition to accurate forestry. Periodic monitoring makes it possible to obtain reliable information on changes in the quality and quantity of forestry resources and allows us to identify factors affecting the dynamics of forest change. The information collected is the basis for strengthening intersectoral relations that can reduce the costs of deforestation, illegal logging, and the costs of forest management, forest fires and the costs of forest mapping. Effective and intensive forest management is becoming increasingly important in the economy of states, since in most countries it is impossible to increase the area of forest land, and their reduction will adversely affect the ecosystem of the earth. Precise forestry is not only a way to reduce costs and increase socio-economic benefits, but also a highly effective environmental tool.

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