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SCENARIO DEVELOPMENT FOR THE IMITATION MODELLING OF FOREST ECOSYSTEM SERVICES

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Sustainable forest management implies the necessity to maintain and uphold the balance between the growing demand for forest ecosystem services and the capabilities present. This issue motivates the development of ways to include various ecosystem services in the forest ecosystem planning and management system, taking into account social, political, environmental, and economic contexts. One of the effective tools for ecosystem service management is imitation modelling, which allows assessing the decision-making risks and consequences. This raises the scientific problem of substantiating possible alternative scenarios for future forested area development for subsequent simulation.

This article is aimed at analysing the approaches to creating scenarios for the development of a forest area for local-level imitation modelling and testing a new method based on the development of the existing approaches to solving this problem. In its first part, modern research analysis in the field of imitation scenario development is presented; the second one proposes a new method for compiling scenarios, created within the framework of the POLYFORES project, and also presents the results of its testing at three model sites located in the Nizhny Novgorod

Region, the Republic of Karelia, and the Moscow Region. For the forest plots of the Nizhny Novgorod Region, four scenarios for forest area development have been created, aimed at obtaining benefits: 1 – from timber harvesting, 2 – from recreational ecosystem services and food forest resources, 3 – from regulating ecosystem services, 4 – both from timber harvesting, under the conditions of intensified forest growing, and from regulating ecosystem services. For forest plots in the Republic of Karelia, the first scenario describes the situation of meeting the demand for wood, while also preserving the biodiversity and regulating ecosystem services; the second and third scenarios take into account the increased demand for wood, with low and high priorities for environmental conservation. For the forest plots of the Moscow Region, only two scenarios were relevant, with the increasing need of citizens for recreational ecosystem services, and the biodiversity preservation priority in management decision-making either remaining low or increasing. For each scenario, forestry activities corresponding to the management objectives have been developed. The proposed scenarios can be used to obtain information about the impact of various management decisions on providing forest ecosystem services.

Keywords: *scenario, forest ecosystem services, key factors, forestry regimes, European part of Russia*

The widely known report «Millennium Ecosystem Assessment» (MEA, 2005) has drawn attention to the concept of ecosystem services (ES). This concept appeared in the 1990s and aims to highlight the impact of ecosystems on human well-being. Currently, this concept is the basis for sustainable ecosystem management and development of cross-sectoral policies (State of Europe's Forests..., 2011; Communication..., 2013; Binder et al., 2017; Kangas et al., 2018). According to this concept, ecosystem services of forests are benefits that people receive from forest ecosystems. Forests provide people with food, wood, and other raw materials for forestry and related industries, regulate climate, water and air quality, form soil fertility, satisfy people's spiritual needs, serve as a place for recreation, provide habitats for biota, preserve biodiversity, etc. (MEA, 2005; The State of the World's Forests..., 2021).

The growing population of the Earth drives an increase in demand for forest resources (Lukina, 2020). According to forecasts, if the current trends continue, global demand for food, wood, water, and energy will increase by 1.5–2 times by 2050 compared to 2010 (Van Vuuren et al., 2015; Riahi et al., 2017). Despite their importance worldwide, forests continue to degrade, and their area is declining. About 13 mln. ha of natural forests are being destroyed annually (The State of the World's Forests..., 2021). This problem is especially relevant for the forests of tropical countries and the boreal zone of Eurasia. The main reasons for the loss are changes in the structure of land use: the development of large- and small-scale agriculture for the production of food products (for example, beef, soybeans, palm oil, cocoa, coffee), mining, urban and infrastructural development (The State of the World's Forests..., 2021). Forest degradation is mainly associated with the loss of biodiversity, which is the provider of all ES. The Red Book index, reflecting the risk of species extinction (a value of 1 indicates the absence of a threat to any species, and a value of 0 indicates the extinction of all species), decreased from 0.82 to 0.73 in the world from 1990 to 2020 (IUCN..., 2020; UN, 2020). At the same time, it is estimated that a decrease in the species richness of wood plants by 10% (from 100 to 90%) will lead to a decrease in forest productivity by 2–3%, and with a reduction in species richness to a single species, forest productivity will range from 26 to 66% of the initial values (Liang et al., 2016; Duffy et al., 2017).

The turning point was 2016: the United Nations adopted the 2030 Agenda for Sustainable Development and approved the Sustainable Development Goals (SDGs), and the Paris Agreement under the UN Framework Convention on Climate Change entered into force. It is recognized that forests contribute to the achievement of almost all SDGs. More specifically, forests are addressed in SDG 15 «Conserve and restore terrestrial and freshwater ecosystems; end deforestation and restore degraded forests; end desertification and restore degraded land; ensure conservation of mountain ecosystems, protect biodiversity and natural habitats; protect access to genetic resources and fair sharing of the benefits; eliminate poaching and trafficking of protected species; prevent invasive alien species on land and in water ecosystems; and integrate ecosystem and biodiversity in governmental planning.». In addition, among the ways to achieve the set goals and the most effective response to global challenges is the development of a closed-loop bioeconomy – an economy that uses renewable biological resources of land and sea for the production of food, bioenergy and bioproducts (Hetemäki et al., 2017; Lukina, 2020). The forest sector is a key player in bioeconomy, which makes a significant contribution to the development of various industries such as construction, bioplastics, packaging materials, food ingredients, textiles, chemicals, pharmaceuticals, and bioenergy. Regulating, cultural, and supportive forest ecosystem services (FES), such as recreation and tourism, water supply, and air purification, are also part of bioeconomy (Transforming..., 2015). Despite the fact that the bioeconomic policy in Russia is in the process of formation, some strategic documents, intergovernmental agreements, or plans also set goals for the transition to a «green» economy, bioeconomy, and a closed-loop economy. Therefore, in Russia in 2017, the president instructed the government «... to provide for the development of strategic planning documents and a comprehensive action plan of the government of the Russian Federation for 2017–2025 as one of the main goals of Russia's transition to an environmentally sustainable development model that allows for the long-term efficient use of the country's natural capital while eliminating the impact of environmental threats to human health...» (List of instructions ..., 2016).

In connection with the adoption of the Paris Agreement aimed at the practical implementation of the provisions of the UN Framework Convention on Climate Change, many countries have included carbon sequestration activities by forests in their national development strategies (Forsell et al., 2016; EPA's Treatment ..., 2018). The voluntary commitments made by the Russian Federation under the Paris Agreement to reduce carbon emissions by 30% from the 1990 level by 2030 encourage the country's government, large domestic businesses, forest users, and the scientific community to find solutions ensuring their implementation with the maximum possible increase in the economic efficiency of industrial production and the mandatory condition of maintaining a balance between forest management systems to ensure a favourable environmental and socio-economic situation in the country. Now the issues of implementing forest climate projects are becoming increasingly relevant, the legislative framework of which has yet to be developed (Scientific debate..., 2021).

The most effective strategy for the transition to the closed-loop bioeconomy, as well as the implementation of the Paris Agreements, is to identify effective innovative ways of sustainable forest management coupled with minimising the risks of making erroneous political decisions. To do this, the consequences of alternative policies and management methods must be assessed (Schmolke et al., 2010). At the same time, scenario modelling is an effective tool for analysing such stability (Messier et al., 2003). The Intergovernmental Platform on Biodiversity and Ecosystem Services (https://ipbes.net/ assessing-knowledge) called the combination of environmental modelling and scenario forecasting the key to improving the understanding of the impact of political attitudes on socio-ecological systems by assessing the relationships, including feedback between direct and indirect objects of change, biodiversity, and ES in general (Morán-Ordóñez et al., 2019). In addition, it makes it possible to take into account the impact of contextual changes, for example, climate change (Duinker, Greig, 2007).

The basic concepts in scenario forecasting are:

«a scenario» is a set of potentially possible, alternative, structurally different situations for the development of the future, due to the current socio-economic, political, and environmental situation in the research area.

«stakeholders» are key players (organisations, groups of individuals, specific individuals) with power, motive, or expressed position that can influence a decision or action.

«the key factor» (driver) is a phenomenon, process, variable, parameter, or trend that affects the further development of the territory and what is happening in it now.

«a storyline» is a description of a scenario that reflects assumptions about the direction, consequence, or result of key factors.

The first step of modelling is to develop scenarios. Scenarios should describe future development trajectories of forest areas in such a way that explicitly takes into account current scientific data, public expectations, assumptions about the main driving forces, relationships, and constraints (Alcamo, Henrichs, 2008). Traditionally, scenario modelling in forestry has been used in strategic forest planning to predict the effects of alternative logging parameters (e.g., Chumachenko et al., 2003; Wikström et al., 2011). Therefore, the simulation scenarios used to be a description of forestry activities that could potentially bring maximum benefit to the user of the forest area for a given period of time. The weak point of such scenarios was taking into account the opinion of only one, sometimes two stakeholders (the forest user and the government), therefore, in such a system, a forest site was often considered solely from the standpoint of acquiring timber resources. All the while for other stakeholders the forest also has ecological, cultural, and spiritual value (Virapongse et al., 2016).

Now the scenarios have acquired a more pronounced social character. There are known works on modelling the impact of urbanization on the provision of ES. The scenarios used are the projected regional scenario of land cover change during urbanization for 2003–2060, based on a spatial model of population distribution (Delphin et al., 2016); assumptions about the rate of urban areas increase (Estoque, Murayama, 2016) or the intensity of development (Sun et al., 2018), which affect the share of forests and arable lands (He et al., 2021). For countries in Africa and South America, there are studies evaluating environmental protection measures to combat poverty (Gauvin et al., 2010; Ferraro et al., 2015). There are studies regarding the impact of forest protection decisions on the provision of FES. For example, in the work of Kärkkäinen et al., (2020), scenarios characterized the limitations of forest management for the conservation of biodiversity; the work (Zarandian et al., 2017) provided an assessment of such management scenarios as the expansion of the boundaries of a protected area to prevent land-use changes and zoning of the territory based on the forecast of the boundaries of protective forests depending on the expansion of urban territories.

The development of scenarios is based on the analysis of key factors of the territory's development. A recent review (Morán-Ordóñez et al., 2019) showed that three-quarters of the studies were conducted for two or more scenarios, while a quarter of the studies used a single scenario, which in most cases was based on climate key factors. The second most popular key factor is forest management (for example, different logging modes, levels of biomass extraction, etc.). Less often, modelling is carried out based on forecasts of fire occurrence and land use change (Morán-Ordóñez et al., 2019). At the same time, global or pan–European studies mainly focus on climate and land-use change as key factors, using storylines based on the IPCC Special Report on Emission Scenarios (Second Assessment Report..., 2014; Nakicenovic, Swart, 2000), national and local studies: on data on fires, other violations, and regime management. Many different storylines and land use forecasts are used in national and local studies: these are either locally defined forecasts or versions of global forecasts with a reduced spatial scale. Often these scenarios are specifically designed to support, develop, and implement local policies. These storylines are either based on collaborative approaches such as workshops or surveys involving local stakeholders or are directly based on local development plans. Sometimes global storylines (for example, IPCC or ALARM) are used as established boundaries within which local key factors can operate. Statistical scaling procedures can be used as well. Many national and local studies rely on hypothetical scenarios, i.e., scenarios that scientists have identified to test their hypotheses, the sensitivity of their models, but that are not informative enough to make a decision. The use of such expert scenarios is not always clearly justified (Morán-Ordóñez et al., 2019).

For Russia, information on the justification of scenarios for modelling is extremely scarce. At the national level, strategic planning in the field of forestry in Russia is carried out on the basis of the Strategy for the Development of the Forest Complex until 2030 (2021). It provides for three scenarios for the development of forestry: inertial, basic, and strategic, which contain information about investment projects and government support measures, measures to minimize risks, forecast export potential, the level of financing of the industry, and the development of the forest industry. Among the quantitative indicators of the development of the forest complex, it contains information on forest cover, logging, afforestation, production of wood products, etc. A detailed discussion of the scenarios is presented in (Development Forecast..., 2012); calculations for them are given in the work (Zamolodchikov, Grabovskij, 2014). The Strategy of Socio-Economic Development of the Russian Federation with Low Greenhouse Gas Emissions until 2050 (Strategy of Socio-Economic Development ..., 2021) provides for two scenarios of socio-economic development of the Russian Federation – inertial and targeted (intensive), which differ in the level of technological development, structural changes (shifts) in the economy, absorption capacity of natural sinks and accumulators of greenhouse gases, and other effects. Short- and medium-term forecasts of socio-economic development published by the Ministry of Economic Development of the Russian Federation (Ministry of Economic Development of the Russian Federation, 2021) can become the basis for constructing scenarios. The forecasts contain information about the dynamics of the production of timber industry products and key factors affecting the projected dynamics of the development of the timber industry. They provide data on industrial production indices for two forecast scenarios: basic and conservative, characterizing the growth rates of the global economy, inflation, and the development of the domestic trading environment (Forecast of Socio-Economic Development..., 2021).

For the regional level, there is data in the literature on forecasting IPCC scenarios adapted for the subject of the Russian Federation (Komarov et al., 2014) and scenarios for the Development Strategy of the Forest Complex until 2030 (Decision Support..., 2019). A recent publication (Leskinen et al., 2020) presented scenarios for climate-smart forestry for three model regions as well: the Republic of Karelia, the Republic of Mari El, and the Angara macrodistrict (Krasnoyarsk Territory). The scenarios, depending on the specifics of the object, included information on fire prevention measures, the intensity and methods of timber harvesting, reforestation measures, and the use of harvested wood for carbon deposition. In the work of Rosenberg (2016) a forecast for the forest cover of the Samara Region was carried out using four scenarios of sustainable development of territories proposed by Costanza (Costanza, 1999), reflecting two extreme positions of politics at the global level: technological optimism and scepticism. It is worth noting that for a qualitative assessment of the stability of each of the scenarios, the author conducted a sociological survey, the purpose of which was to assess the comfort of human life under one or another hypothetical scenario line.

For objects at the local level, scenarios for the development of a forest area are most often drawn up to test a particular scientific theory. The rationale for using such expert scenarios is not explicitly indicated, therefore, their use for making managerial decisions is difficult. For example, simplified options of the timber harvesting system are used for scenario modelling: a scenario without forestry activities; performing selective logging followed by natural reforestation; conducting clear cuttings followed by artificial reforestation (Chumachenko et al., 2020; Kolycheva, Chumachenko, 2020). In the work by Shanin and co-authors (Shanin et al., 2012), four scenarios were used: natural development of the territory; a scenario that takes into account the occurrence of forest fires; a scenario of two thinnings followed by selective cutting; a scenario of four thinnings followed by clear cutting. Kiseleva and co-authors (Kiseleva et al., 2021) modelled ten scenarios that differ in the intensity of use of the allowable felling rate, the proportion of artificial reforestation, the mode of care, etc.

It is worth noting that the development of scenarios for local-level objects is very relevant. Local and subnational scales are ideally suited for a comprehensive analysis of processes operating at different levels, which, in turn, is crucial for assessing the sustainability of ecosystems in the face of global change and, thus, for guiding sustainable development policies (Seidl et al., 2011). For this reason, local scales have been proposed as one of the starting points for creating scenario structures for environmental scenario planning (Kok et al., 2017). Thus, the development of authoritative, comprehensive scenarios for the future development of forests, management methods and risks becomes an urgent need.

Despite the fact that the justification of scenarios for the development of a forest area for environmental management is an important task, currently the development of scenarios for local-level simulation does not contain an analysis of the prevailing objective conditions, circumstances, and opinions of stakeholders. Most often, the used scenarios are a simple iteration of solutions, which does not insure against making managerial mistakes.

The work objective of this paper is to analyse approaches to the development of scenarios for the development of a forest area for local-level simulation, to propose and test a new method based on the development of existing approaches to solving this problem, including economic, environmental, social, political, and technological features of a forest area at the local/landscape level.

1. Analysis of methods for developing scenarios for the development of a forest area

1.1 Basic concepts and concept of the scenario approach

There are many definitions of the word «scenario». For example, Hermann Kahn, one of the founders of future research and the father of scenario planning, defines a scenario as «a set of hypothetical future events created to clarify a possible chain of causal events, as well as their decision points» (Kahn, Wiener, 1968); or scenarios are a description of a future situation and course of events, making it possible to move on from the current situation to the future (Godet, 2000); scenarios are also defined as alternative futures resulting from a combination of trends and policies (Fontela, Hingel, 1993). The analysis of the literature data reveals two approaches to its definition: (1) allocation according to the principle «scenario is a probabilistic event» (Porter, 1985; Jarke et al., 1998; Cornish, 2004; Van der Heijden, 2011); (2) allocation according to the principle «scenario is a method or tool» (Schoemaker, 1995; Schwartz, 1996). However, they all perform one of two functions: the function of risk management, in which scenarios make it possible to test management strategies and avoid possible negative consequences, and the creation of a creative product to generate new ideas (Lang, 2001).

One can depict the idea of a script using the so-called scenario funnel (Von Reibnitz, 1987; Pillkahn, 2008; Glenn, Gordon, 2009). Starting with a more or less well-known situation in the present, the space for alternative development of the future increases as one looks far into the future, i.e. the funnel expands. When one «looks» into the near future, the situation will be very similar to today, but in the distant future, the probability of a change in the situation increases. The current trends may change, and even the factors that have been decisive so far may change the direction of action or lose their significance. If one «cuts» a funnel at some stage, all potential future situations (scenarios) lie somewhere on the surface of the slice of this funnel.

The scenarios have the following characteristic features (Steinmüller, 2012):

- Scenarios are always hypothetical: they are based on reasonable assumptions about cause-and-effect relationships and combine them into a comprehensive structure (a model nature).
- Scenarios illustrate opportunities, potential events, and future situations, the implementation of which is not necessary, but possible.
- Scenarios are free from internal contradictions. The basic assumptions of the scenario (causal sequence, structure, and postulated facts) must be compatible with each other.
- Scenarios are always thematically focused, specific, and, therefore, they may omit some aspects. They will never be able to describe the future situation in its entirety, scope, aspects, or ramifications. They should limit themselves to this subject and its immediate environment and describe it with a degree of detail sufficient to implement the tasks of the forecast.

There is a wide variety of scenario classifications. Börjeson and co-authors (Börjeson et al., 2006) described nine typologies of scenarios in their work and proposed a typology that is very popular today. The authors distinguish three categories of scenarios based on questions that can be asked about the future: «what will happen?» (predictive), «what can happen?» (research), and «how can a specific goal be achieved?» (normative). Each of the categories is divided into two types. Predictive scenarios consist of types that differ in the conditions they impose on what will happen: The «forecasts» type answers the question – «what will happen if the probable course of events is realized?», the «what if?» type answers the question: «what will happen in case of certain events?». Research scenarios are divided into two types: external scenarios and strategic scenarios. External scenarios answer the question: «what can happen with the development of external factors?»; strategic scenarios answer the question: «what can happen if we act in a certain way?». Normative scenarios consist of two different types, differing in how the structure of the system is interpreted: preservation scenarios answer the question «how can the goal be achieved by adjusting the current situation?», and transformation scenarios answer the question «how can the goal be achieved when the prevailing structure blocks the necessary changes?». Research and regulation scenarios are of interest for modelling socio-ecological systems (Schüll, Schröter, 2013).

Parties involved in the development of scenarios are stakeholders (Seppelt et al., 2011; Oteros-Rozas et al., 2015) – «those who influence or can influence a decision or action» (Reed et al., 2013). In the context of scenario development, stakeholders can be represented by an organization, a group of people (e.g. loggers), and specific individuals. The criteria by which a stakeholder can be identified are responsibility, influence, partnership, dependence, representativeness, and orientation (Account Ability, 2005). Stakeholder engagement in scenario development has a wide range of potential benefits, mainly improving the quality and relevance of scenarios by incorporating diverse perspectives and knowledge, empowering stakeholders, promoting common understanding, and helping to enhance the perceived legitimacy and ownership of outcomes (Berkhout et al., 2002; Cash et al., 2003; Pahl-Wostl, 2008). A wide range of qualitative and quantitative methods of participation can be used to facilitate the involvement of stakeholders in the development of the scenario. These include: seminars (e.g. Jungk, 1997), stakeholder engagement based on scenarios based on simplified discussion and ranking (Tompkins et al., 2008), interactive discourse (e.g. Renn, 2006), multicriteria assessment (e.g. Madlener et al., 2007 Kowalski et al., 20 09), conceptual system modelling (e.g. Magnuszewski et al., 2005), and modelling of indirect or dynamic systems (Bousquet et al., 2002; Van den Belt, 2004; Castella et al., 2005). A number of visualization techniques are used to present scenarios to stakeholders (e.g., Sheppard, Meitner, 2005; Sheate et al., 2008; Soliva et al., 2008). Although all the presented methods ensure the involvement of stakeholders in the scenario development process, the degree of their participation varies in terms of timing and type of interaction (Reed et al., 2013; De Vente et al., 2016). For example, stakeholder participation can range from the predominantly one-sided consultation processes that dominate the literature on environmental scenarios (Oteros-Rozas et al., 2015) to collaborative processes in which researchers and stakeholders coordinate the scenario development process to ensure that the outcome meets their needs (Wollenberg et al., 2000; Pahl-Wostl, 2008; Volkery, Ribeiro, 2009; Henrichs et al., 2010). A detailed analysis of stakeholder engagement in the scenario development process is presented in (Andersen et al., 2021).

The purpose of the scenarios is to form an orientation towards the future development of the territory by observing certain relevant key driver factors. Key factors are the main causes of changes in the future, which fall into a number of broad categories, sometimes called STEEP (Bowman, 1998; Ho, 2014). STEEP is an abbreviation of the social fields: «society», «technology», «economy», «ecology», and «politics». Structured and described assumptions about the interaction between different drivers define the logic of the scenario and underlie its storylines.

Storylines are a qualitative and descriptive component of the script, creating images of the future. They may reflect assumptions in scenarios about changes in key factors, or they may describe the consequences or outcomes of a scenario (Rounsevell, Metzger, 2010). The storylines of the scenario play an important role when there is a limited understanding of the cause-and-effect relationships within the system. Although the storylines of the scenario are descriptive, they do not predict the future. The purpose of creating storylines is to stimulate, provoke, and convey visions of what the future may hold (Rounsevell, Metzger, 2010). Many different methods are used to plot the scenario, although most of the examples used to assess environmental change are exploratory and are determined using matrix logic that reflects various aspects of the key factors influencing environmental change (see the next section). There are works that provide practical advice on the development of storylines narratives (NPS, 2013; Rowland et al., 2014).

Environmental studies use three criteria for the quality of scenario development: their significance («do the scenarios meet information needs?»), reliability («are the scenarios scientifically sound?»), and legitimacy («who developed the scenarios and how?») (Rounsevell, Metzger, 2010).

The following criteria are also used to verify already developed scenarios (Kosow, Gaßner, 2008; Amer et al., 2013):

• Plausibility: scenarios should be possible.

• Consistency: a scenario must be internally logical and cannot contain contradictory or mutually exclusive elements.

• Relevance: scenarios should contribute to understanding the question posed.

• Creativity: scenarios should open up new and original perspectives.

• Differentiation: scenarios should be structurally distinct and differ from each other.

1.2 Methods of scenario development

The basis for the development of scenarios is the key factors. Not all key factors have the same characteristics. To evaluate them and identify the critical drivers that are most informative and important for scenario design, three methods are described in the literature: the two-dimensional Wilson matrix, the method of cross-impact analysis, and structural analysis.

The two-dimensional Wilson matrix ranks all factors into two categories: the potential impact and the likelihood that the factor will develop into a serious problem (Pillkahn, 2008). The matrix is a table where the rows indicate the degree of probability of the factor, and the columns indicate the degree of potential impact (the ranks assigned to the factor correspond to «high», «medium», and «low» degrees). The most important key factors for creating scenarios are displayed in the upper right corner of the matrix. These key factors are used to build scenarios.

Cross-impact analysis methods are used to determine important chains of possible events and the extent to which the occurrence of each possible event changes the likelihood of others (Gordon, Hayward, 1968; Enzer, 1972). In this case, the key facts are written out in rows and columns of the matrix. A cell at the intersection of two factors is assigned a value from 0 to 3 (0 – no influence; 1 – weak relationship; 2 – medium relationship; 3 – strong relationship), indicating the degree of influence of the first factor on the occurrence of the second. To build scenarios, the factors with the highest number of points are selected. These factors most of all influence the occurrence of certain events.

The principle of structural analysis (Wilms, 2006; Kosow, Gassner, 2008; Glenn, Gordon, 2009) is similar to the principle of the method of cross-effects, but it is aimed at assessing the interdependence of factors. Structural analysis is carried out by evaluating the relative influences of key factors, i.e. for each factor, it is estimated how strongly one key factor affects other key factors, and vice versa, how strongly other factors influence it. A matrix of factors is constructed, where for each pair of factors the question is asked «how much does one factor affect the other?» (row) or «how much is one factor influenced by another factor?» (column). In this case, the orientation (positive or negative) is not taken into account. The same scale is used to assess the impact as in the cross-exposure method. The sum of the points in the rows shows the activity of the factor, in the columns – passivity. Critical, dynamic, or relay factors (factors with high passivity and activity) are used to build scenarios. These factors are very influential and, at the same time, very dependent. They are connected to a network of other factors and by their nature are factors of environmental instability since any action on them has consequences for other factors under consideration.

Critical key factors selected by such methods are used to build scenarios. The analysis of the literature data revealed three main methods of constructing scenarios: the cross-matrix method, morphological analysis, and the event tree.

The cross-matrix method (or 2×2 matrix) is appropriate when driver analysis shows that two criteria or factors are sufficient to determine the future development of the territory (Schwartz, 1996; Pillkahn, 2005, 2008; Kosow, Gassner, 2008). It is borrowed from the field of strategic planning of the organization and is similar to the Thompson–Strickland matrix (Thompson, Strickland, 1995). This is a simple method of creating high-quality scenarios that can describe complex storylines that are interesting and understandable to interested parties. The matrix is formed from a combination of the main or extreme values of two key factors. It consists of four squares formed by vertical and horizontal axes: the vertical axis is the extreme values of the first key factor, and the horizontal axis is the extreme values of the second key factor. Thus, four independent scenarios can be obtained.

Morphological analysis (Heinecke, 2006) is a method used to narrow down the number of all possible combinations of key factors by determining which combinations are plausible and thus can play a role in constructing consistent scenarios. This is crucial to ensure the credibility of the scenario (Gaßner, 1992). This step is carried out by developing a discrete space of manifestations of the key factor and determining the relationships between the manifestations based on internal consistency. Such a manifestation space is called a morphological field (Ritchey, 2009). It is a matrix where key factors are recorded in a row, and their corresponding manifestations in the future are in columns. Then the consistency of all combinations of manifestations is evaluated, that is, it is estimated how well each manifestation coincides with all manifestations of another factor.

The Event Tree Analysis (ETA) method (Andrews, Dunnett, 2000; Traynham, 2010) is less common for scenario development in environmental planning than the two previous methods. In the classic version, the scenario tree consists of three elements: squares, meaning decision-making, circles, characterizing possible events, and branches. The branches coming out of the square represent possible solutions, and those coming out of the circle represent the results. When planning a scenario, it is necessary to consider combinations of risky events, each of which will be a separate scenario. In environmental planning, ETA is used to identify and analyse the sequence (options) of the development of catastrophic events, including complex interactions between events. The probability of each scenario of catastrophic events is calculated by multiplying the probability of the main event by the probability of the final event.

Structural analysis to identify key factors and morphological analysis to construct scenarios is at the heart of the well-known approach developed in the INTEGRAL project (Schüll, Schröter, 2013). This approach has been successfully tested in 20 case studies in European countries to develop scenarios for the future development of ES at the landscape level (Hengeveld et al., 2017). Thus, the development of scenarios, according to this project, consists of five stages:

1. Definition of the scenario space. This is a common limitation of a research question at the beginning of the research process in order to cut off variables that are not relevant to the research. The limitations of the time range, geographical and thematic coverage are important. The identification of factors influencing the choice of a particular path of development of the object of study will depend on the definition of the scenario space in the future.

2. Identification and selection of key factors. At this stage, the key factors are identified, selected, and displayed in the STEEP table (society, technology, economy, ecology, and politics), while the factors are divided according to their level of occurrence into micro (research level), meso- (national), and macro- (international). The rationale for including the factors in the list is their supposed importance for the field of study, i.e. they should all act at the micro level. A glossary of factors is compiled. The process can be organized based on the analysis of literary data, expert opinions, brainstorming in the research group, and other methods available to the researcher. Critical factors are identified from the array of key factors by structural analysis. The Parmenides EIDOS product, the Situation Analysis software module, is used in this process (https://www.parmenides-eidos.com/eidos9/us/).

3. Description of alternative future manifestations. Possible future values of selected key factors are created here. At the beginning of this stage, it is recommended to group the key factors. The results of the aggregation of key factors are called «elements». The various directions of change that these elements may demonstrate in the future are called «manifestations». For example, manifestations of the key factor «population» can be «stagnation of population growth», «population growth», and «population decline». However, the creation of several future manifestations is not necessary. Sometimes there is a constant trend (stable and continuous change) without any indicators of change. Another option is the immutability of the manifestations of the factor.

4. Combination of factors and assessment of consistency. The next step is to evaluate how well each individual manifestation of each element combines with the manifestations of all other elements in the scenario. This task is implemented in the Parmenides EIDOS program, based on

morphological analysis. The result of the stage is «raw scenarios».

5. Clustering of coherent combinations (scenarios).

More or less consistent combinations of manifestations (scenarios) can be displayed on the cluster map using Parmenides EIDOS. The distribution of scenarios shows how different or similar they are to each other, and helps to select the original scenarios. The result is displayed as a two-dimensional scenario distribution, in which the position of each scenario in relation to other scenarios depends on their similarity.

6. Scenario development. At this stage, scenario storylines are created taking into account the interests of the target group. Storylines are discussed with stakeholders. The means of creation can be short stories, illustrations, or other forms of storytelling.

7. Transfer of scenarios. The last step is thinking about how scenarios can help make a difference in practice. In INTEGRAL, they serve as a starting point for normative tasks for retrospective analysis. They can also be a starting point for developing policy documents and strategies for specific recipients.

Thus, social and environmental planning uses a few methods to develop scenarios. All of them allow constructing qualitative scenarios and are based on the identification of key factors and the analysis of their probabilistic manifestations. The choice of a method for constructing scenarios depends on the research goal, the number of identified drivers, and the analysis budget. For example, the construction of an event tree is used to analyse the risks of catastrophic events, and the cross-matrix method and morphological analysis are used to analyse the future development of the territory. At the same time, morphological analysis is more laborious than the cross-matrix method, and it is difficult to conduct it in full without appropriate tools.

2. Development and testing of the method proposed in the POLYFORES project

2.1 Objects of research

Scenarios were developed for three objects located in the Republic of Karelia, in the Moscow and Nizhny Novgorod Regions (Table 1). The choice of model objects is determined by differences in natural and climatic conditions, the purpose of forests, and their role in the socio-economic development of the studied territory.

Table 1. Characteristics of the research objects

Object	Average indicators of the stand			FVC, share of the land area	share of protective forests	Types of land use, timber processing infrastructure
	Stock composition	Age, years	Densit y			
Forest plots in the Moscow Region	60% *Betula* sp., 20% *Picea abies*, 10% *Pinus sylvestris*, 10% *Populus tremula*, singular *Quercus robur*, *Tilia cordata*	53	0.73	39% – C3; 21% – C2, 21% – B2; 12% – B3	100%	Forest recreation. There are no timber processing enterprises.
Forest plots in the Nizhny Novgorod Region	50% *Pinus sylvestris*, 30% *Betula* sp., 10% *Populus tremula*, 10% *Picea abies*, singular *Quercus robur*, and *Tilia cordata*	58	0.67	51% – B2 15% – B3	63%	Harvesting of wood for the production of lumber, harvesting of mushrooms, berries, forest recreation. 6–7 small sawmills.
Forest areas in the Republic of Karelia	50% *Betula* sp., 30% *Picea abies*, 20% *Pinus sylvestris*, singular *Populus tremula*, *Alnus glutinosa*	61	0.69	33% – B3; 16% – C3	24%	Harvesting of wood for the production of lumber, paper, pellets; harvesting of berries, mushrooms. Central Processing plant, 8–9 sawmills, pellet production.

The first object is the Dankovskoye district forestry of the Moscow Region, which is part of the Russian Forest forestry (hereinafter referred to as the object in the Moscow Region) located in the zone of coniferous-deciduous forests. The area of the forest area is 6.837 hectares. The forest cover is dominated by pioneer species – birch (*Betula* sp.), scots pine (*Pinus sylvestris* L.), and aspen (*Populus tremula* L.). Coniferous species (pines and spruces) account for 30% of the total number. The admixture contains petiolate oak (*Quercus robur* L.), heart-shaped linden (*Tilia cordata* Mill.). The average age is 53 years, the density is 0.73. Types of forest vegetation conditions (FVCs) according to the Vorob'ev-Pogrebnyak classification (Vorob'ev, 1953) on the territory of the forestry have a wide range from A2 to C4, but dominant conditions have been identified among them: 39% of the area of the forestry is represented by type C3, 21% – FVC C2 and B2, 12% of the territory – FVC B3. At the moment, the territory belongs to protective forests; the category of protection is forests that perform the functions of protecting natural and other objects; almost half of them are green zones, and the second half are forests located in the forest park area of Serpukhov. Only sanitary cutting is carried out at the object, food forest resources are used for the population's own needs, there are no large industrial fees. There is no production processing wood and non-wood products of the forest.

The second object is separate parts of the Kroshnozersky and Svyatozersky precinct forestry districts of the Pryazhinsky forestry of the Republic of Karelia (hereinafter referred to as the object in the Republic of Karelia), forming the Manga River catchment area. The object is located in the middle taiga zone. It covers an area of 16.755 hectares. Coniferous and small-leaved communities from *Betula pendula* Roth*., Picea abies* (L.) H.Karst., *Pinus sylvestris* L., and *Populus tremula* L. The share of conifers is 50% of the stock. The average age is 61 years, the density is 0.69. The predominant FVCs are B3 – 33% and C3 – 16% of the total area of the object, the rest of the territory is occupied by various types of forest growing conditions from A1 to C4. Seventy-six percent of the territory belongs to operational forests, on which 93% of the total wood stock of the site grows. Forestry on the territory of the research object is of strategic importance. Enterprises of the forestry, woodworking, pulp and paper industry, production of building materials, wooden houses are located here. The local population is harvesting food forest resources on the territory of the object. The Republic of Karelia is also one of the largest industrial producers of wild berries (Wild Berries Market in Russia ..., 2021). At the same time, the forests of the Republic of Karelia are of great importance for the formation and regulation of the water balance. A unique developed hydrographic network has been formed in Karelia. The lake content of the territory is 21%, being one of the highest in the world. Most of the waters of the Ladoga and Onega Lakes, which are the largest freshwater reservoirs in Europe, are located in the Republic (Litvinenko et al., 2011).

The third object is separate parts of the Staroustinsky District Forestry of the Voskresensky District Forestry of the Nizhny Novgorod Region, leased for the purpose of harvesting wood and farming to Gray Horse Breeding Plant LLC (hereinafter referred to as the object in the Nizhny Novgorod Region). The object of the study is located in the southern taiga zone. The area is 8.512 hectares. The forests are dominated by coniferous-small-leaved derived communities from *Pinus sylvestris* L., *Betula pendula* Roth., *Popolus tremula* L., and *Picea abies* (L.) H. Karst. The admixture contains *Quercus robur* L. and *Tilia cordata* Mill. The proportion of conifers is 60% of the stock; age is 58 years, the density is 0.67. The ratio of the areas of operational and protective forests is 37:63; at the same time, 34% of the wood stock is located in operational forests. Protective forests in most cases belong to the following categories: forests located in water protection zones, valuable forests, forbidden forest strips located along water bodies and spawning forest strips, and forests located in specially protected natural areas. The research object is located in an industrially developed region with high transport accessibility, where timber harvesting is one of the main sources of income for the local population. About 6–7 small sawmills are located in the immediate vicinity of the research object.

2.2 The research method implemented in the POLYFORES project

Taking into account the weak and strong points of the approaches described above, the POLYFORES project has developed a method that is a synthesis of structural analysis and the cross-matrix method. The steps similar to those recommended in the INTEGRAL project were taken as a basis (Schüll, Schröter, 2013).

The development of the scenarios was carried out in several stages:

1. Definition of the scenario space, during which the time horizon of the scenarios and the geographical scale of their action were established.

It is generally believed that long-term planning plays a key role in forest management decisions (Van Notten et al., 2003) since the total duration of forest development exceeds the usual planning horizons in other areas (Hoogstra, Schanz, 2009). Therefore, the study adopted planning for a period of up to 100 years. The timing of the study is determined, among other things, by the calculations of climate change in the IPCC assessment reports (IPCC, 2013, 2014).

Scenario concepts can be formed at various geographical levels. For example, there are four geographical reference points for scenarios: global, international, national, subnational, and regional levels (Greeuw et al., 2000). In both environmental and social sciences, the landscape is recognized as a unit combining biogeographic conditions, ecological processes, and social scales (Görg, 2007; Turner, 2015). For many ES, social, political, and environmental processes interact with landscape models created by the management decisions of several different forest owners (Görg, 2007; Turner, 2015; Seidl et al., 2015; Van Oosten, 2017). Thus, for ES management, the landscape level, defined on a scale as the level between the forest management unit (in Russia it is an allocation) and the region, is optimal for studying. The sizes of the objects in Karelia, Moscow and Nizhny Novgorod Regions are 16.755, 6.837, and 8.512 hectares, respectively. These areas correspond to the landscape/local modelling level. In this case, local and regional factors affecting the forest management regime of the territory will be a priority. At the same time, it is assumed that they will combine the driving forces and barriers at the national and global levels.

In the study, the thematic coverage will cover all issues that may affect the development of forest plantations in the studied territories.

2. Identification of key factors.

Various tools for determining key factors have been selected for the research objects, but all of them are aimed at identifying the following drivers of territory development: (a) prioritisation of FES, (b) local specifics (what can affect the utilisation of FES?) (c) possible issues (what prevents the utilisation of FES?), (d) needs (what is lacking for the utilisation of FES?). The justification of the priority key factors was carried out in accordance with the identified drivers of the development of the area within the framework of the same tools.

The selection of stakeholder groups to identify key factors was based on proposals to involve stakeholders to support decision-making in the field of natural resource management (Harrison, Qureshi, 2000). According to these proposals, it is recommended to involve three groups of stakeholders: (1) those who are primarily influenced by decisions; (2) those involved in informing the decision-making process and (3) those involved in the implementation or management of the decision-making process.

The selection of stakeholders was carried out in three stages. (1) Identification of stakeholders. The snowball method was used to map stakeholders in the case of the object in the Nizhny Novgorod Region. It involves the use of an initial list of stakeholders, which is then supplemented by proposals from the involved stakeholders. In the case of objects in the Moscow Region and the Republic of Karelia, a targeted selection (focus group) was used, which involves inviting already well-known and well-established persons. (2) The distribution of stakeholders into groups was carried out by the stakeholders themselves, depending on their self-perception, under the guidance of the authors of the article. One person could only enroll him/herself in one stakeholder group. (3) The study of relations between interested parties (identification of obvious conflicts and sympathies) was carried out using a two-dimensional matrix, where in a cell at the intersection of two potential persons, the authors of the article, based on preliminary interviewing, write out the value of the degree of conflict or sympathy on a five-point scale from -2 to +2, where a negative value indicates conflict, a positive value indicates sympathy. The people who scored the highest negative or positive amounts did not participate in the study. For more information on the methods of selecting stakeholders, see (Reed et al., 2009). The optimal number of stakeholders is 10 to 30 people (Andersen et al., 2021).

The differences in the methods of involving stakeholders and the methods of developing scenarios at the objects are explained by the high labour costs for performing a complex of works for the object in the Nizhny Novgorod Region.

For example, a one-day workshop with the involvement of interested parties was organized at the object in the Nizhny Novgorod Region. The seminar was attended by 25 people (7 women, 18 men) (Table 2). During the seminar, interviews, a business game, and a moderated open discussion were conducted. The results were surveyed and annotated in order to further develop a description of the scenarios.

A working group has been formed for the objects of the Moscow Region and the Republic of Karelia, consisting of specialists in the field of ecology (3 people), forest legislation (1 person), forest management (3 people), and local residents (4 people). Of these, 5 were women and 6 were men. The composition of the working group changed only in terms of representatives of local residents. The sexual distribution of the locals was identical. The age distribution was not taken into account. Based on the analysis of literature and open web sources, a brainstorming session was conducted, as well as a structured group discussion.

Table 2. Groups of stakeholders that participated in the workshop

A group of stakeholders	Type of stakeholder	Number of people
Forest users and timber processors	Lease holders	3
	Timber processors	2
Representatives of the municipal government	Representatives of municipal administration	2
	Representatives of the Public Council	1
Non-governmental organizations	Representatives of environmental non-governmental organizations	2
The governing bodies of the Russian Federation and the subjects of the Russian Federation	Managers	3
Local residents	Hunters	2
	Tourists and vacationers	2
	Mushroom and berry pickers	2
Other	Clergy	1
	Media representatives	2
	Government representatives	1
	Scientists	2
Total:		25

The identified key factors for the objects of research were discussed at the All-Russian conference «Scientific Foundations of Sustainable Forest Management» (Tebenkova et al., 2018) and the scientific seminar «Multipurpose Use of Forests and Forest Legislation» (Scientific approach..., 2019), held as part of the debates of the Scientific Council of the Russian Academy of Sciences on forests. A glossary of the identified key factors has been compiled.

3. Selection of key factors and their grouping.

The selection of key factors was carried out using structural analysis. After identifying the factors of environmental instability, they were grouped according to the coincidence of the action vector in two directions. In addition, the researchers proceeded from the assumption that the directions were independent, so the grouping of factors in the direction was carried out taking into account the obvious co-dependency.

4. Development of the scenario matrix (political scenarios) and their description.

The cross-matrix method was used for the direct development of scenarios. A working group formed at the CEPF RAS analysed the realism of each of the four scenarios and developed a description that includes a narrative about the state of the market for priority forest resources, legislative initiatives, and forest management strategies.

5. Development of forestry regimes (forestry scenarios).

This stage of the study answers the question: «What should be the strategies or decisions of forest management entities, taking into account alternative policy scenarios?». A system of forestry measures (forestry scenarios) has been developed, including logging, reforestation, and forest care, which will be carried out under one or another political scenario for the future development. In addition, forestry scenarios included aspects of land-use strategies that affect forest management. The developed forestry scenarios are the input information for mathematical simulation models, therefore, the set of forestry operations takes into account the requirements of the RUFOSS mathematical model integration module (Certi-ficate No. 2020666245 dated December 8, 2020). The program developers participated in the work of the expert group on the development of forestry scenarios. The developed forestry sce-narios are not exhaustive. Several forestry sce-narios may correspond to one political scenario.

2.3 Results and discussion

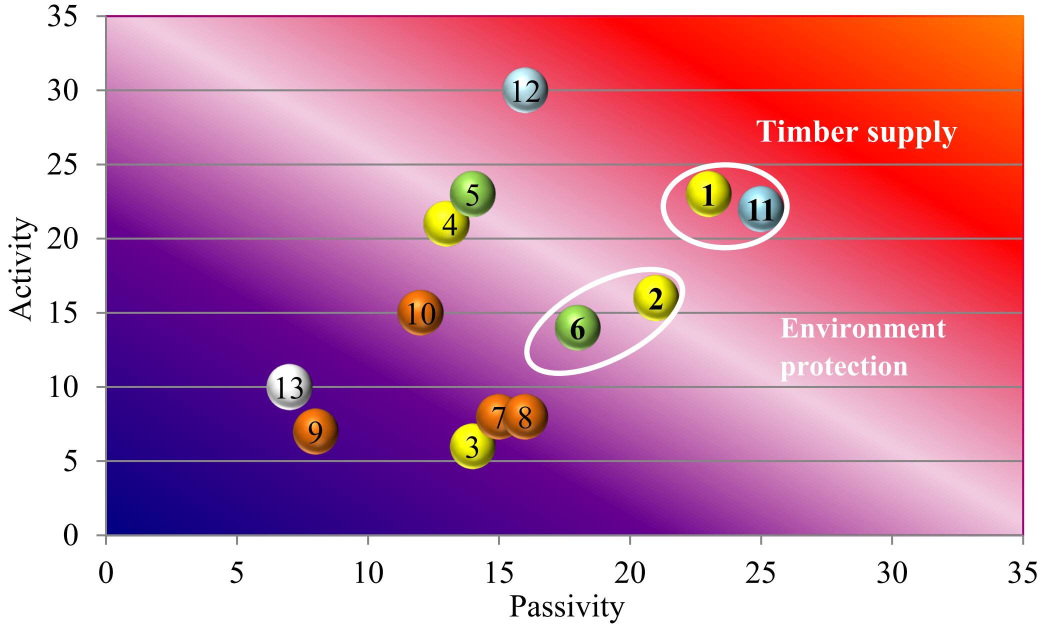
Key factors. During the work of the seminar and the expert group, fourteen key factors were identified for the research object in the Nizhny Novgorod Region, fifteen for the object in the Republic of Karelia, and ten key factors for the object in the Moscow Region. The identified key factors are included in the STEEP table (Table 3).

For all objects, most of the factors belong to the social group, of which such factors as «recreation of the population» and «food forest resources» are characteristic for each object. Environmental factors such as «fires and forest disasters», «protection of species and ecosystem functions» were also identified for all objects. Only one economic factor is common to all objects – the «development of the forest tourism market», which at the object in the Moscow Region does not include making a profit from hunting for the purpose of recreation.

The object-specific key factors for the object in the Moscow Region were formed, taking into account the proximity of the object of study to the densely populated Moscow agglomeration and the location near the city of Serpukhov. The forest area under study is designed to maintain a favourable environmental situation in cities and create recreation areas for the urban population. Such factors include «construction on forest lands», «load from urban settlements», «protection of water and air». Significantly more economic factors have been identified for objects in the Nizhny Novgorod Region and the Republic of Karelia than in the Moscow Region. Due to the high forest cover and the availability of operational forests, forestry in these regions is characterised by profit from harvesting and processing of wood. There is a well-developed timber processing industry, which is absent in the Moscow Region. In addition, harvesting of forest food resources can be a significant source of income for the local population.

Table 3. The list of key factors for the objects of research

Object	Economic	Environmental	Social	Political	Technological
Forest plots in the Moscow Region	1. forest tourism market	1. protection of water and air 2. protection of species, their habitats, and ecosystem functions 3. fires and forest disasters	1. construction on forest fund lands 2. recreation of the population 3. burden of urban settlements 4. food forest resources	1. forest management plans 2. regulation, laws	
Forest plots in the Nizhny Novgorod Region	1. wood market 2. forest tourism market, including hunting 3. market of food forest resources 4. cost of renting a plot	1. fires and forest disasters 2. protection of species and ecosystem functions	1. wood for local residents 2. recreation of the population 3. food forest resources 4. monopolization of forest management by state authorities, bureaucratization	1. forest management plans 2. regulation, laws	1. wood processing technologies
Forest areas in the Republic of Karelia	1. wood market 2. forest tourism market, including hunting 3. market of food forest resources 4. bioenergy, paper, and pulp market 5. rates of payment for the use of the forest	1. protection of water and air 2. fires and forest disasters 3. protection of species, their habitats, and ecosystem functions	1. wood for the local population 2. recreation of the population 3. food forest resources 4. monopolization of forest management by state authorities, bureaucratization	1. forest management plans 2. regulation, laws	1. forest road network 2. bioenergy and paper production



- 1 timber market
- 2 forest recreation market (including hunting)
- 3 forest food resources market
- 4 plot rental cost
- 5 forest fires and calamities
- 6 species, habitats and ecosystem functions protection
- 7 local populace demand for timber
- 8 individual recreation
- 9 forest food resources
- 10 monopoly on forest management by government agencies; bureaucratisation
- 11 forest management plans
- 12 laws and regulations
- 13 wood processing technologies

Figure 1a. Structural analysis of key factors for objects in the Nizhny Novgorod region

Factor colors: yellow - economic, green - environmental, red - social, blue - political, white - technological

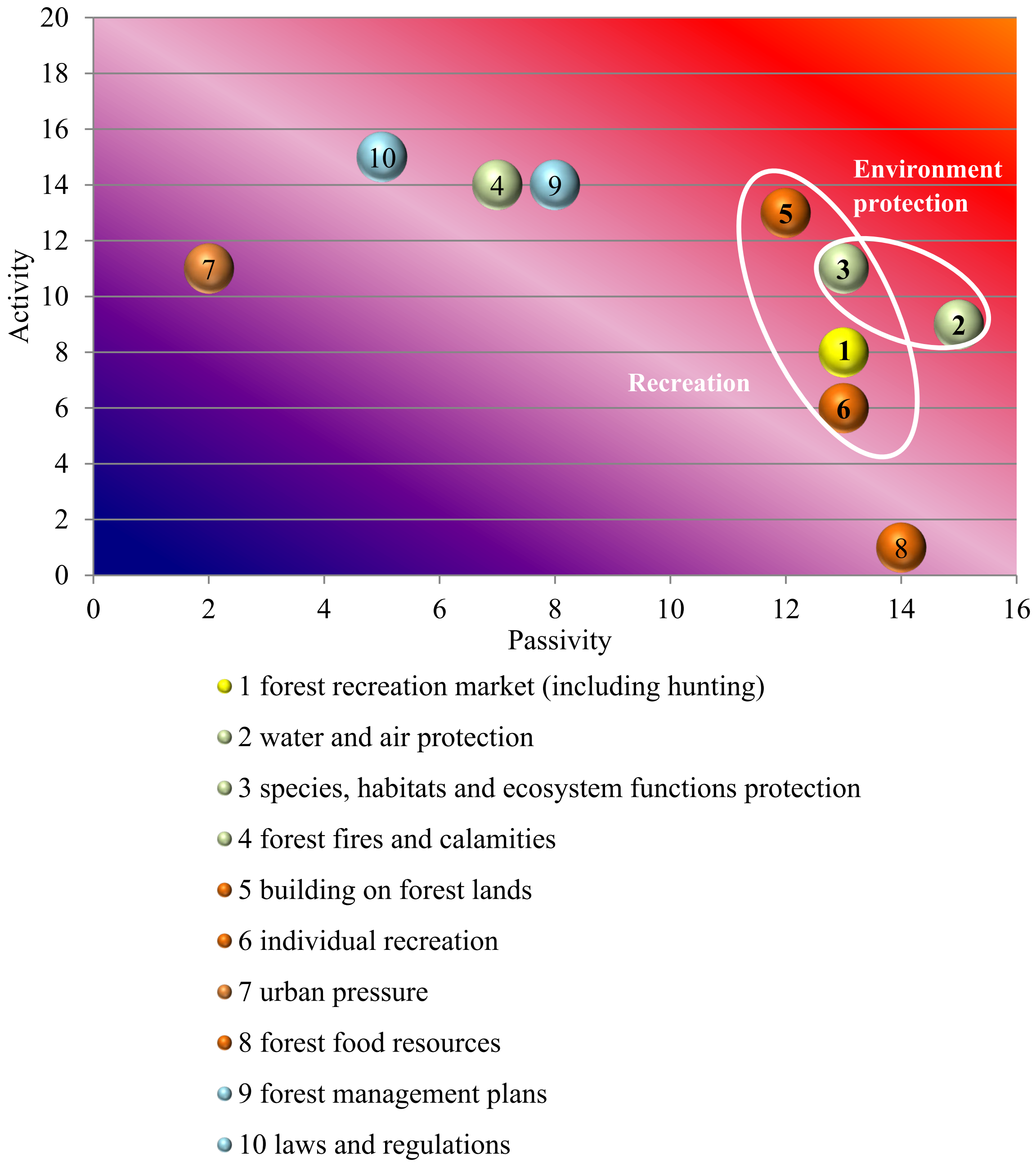
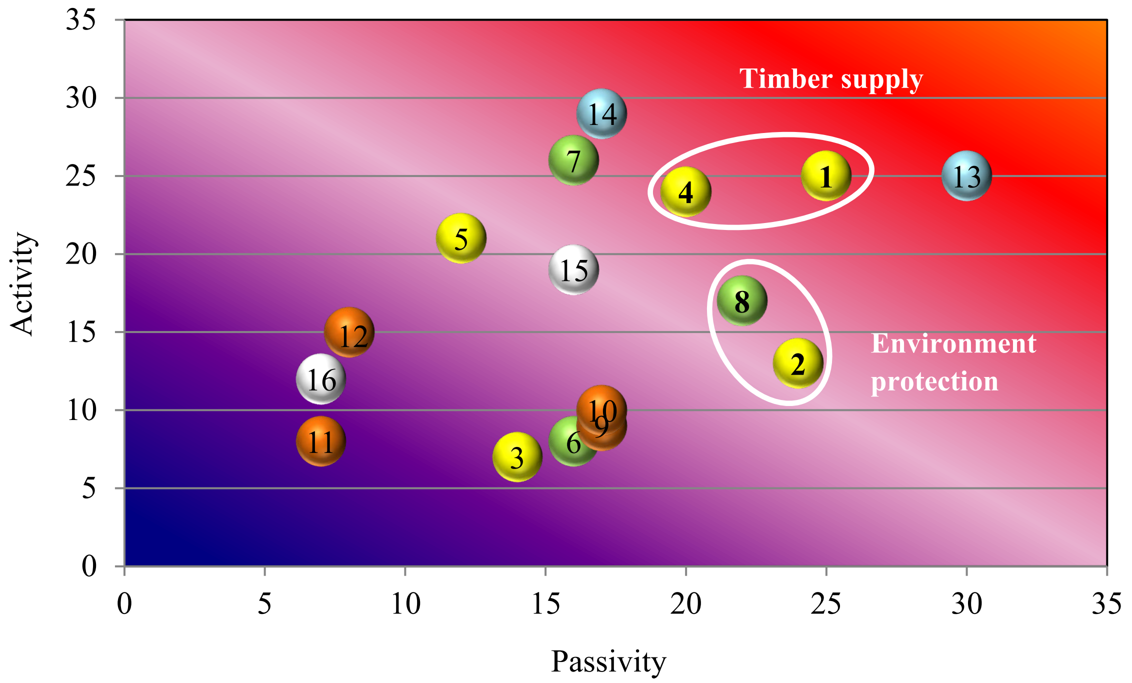


Figure 1b. Structural analysis of key factors for objects in the Moscow region

Factor colors: yellow - economic, green - environmental, red - social, blue - political, white - technological



- 1 timber market
- 2 forest recreation market (including hunting)
- 3 forest food resources market
- 4 bioenergy, pulp and paper market
- 5 forest use fees
- 6 water and air protection
- 7 forest fires and calamities
- 8 species, habitats and ecosystem functions protection
- 9 local populace demand for timber
- 10 individual recreation
- 11 forest food resources
- 12 monopoly on forest management by government agencies; bureaucratisation
- 13 forest management plans
- 14 laws and regulations
- 15 forest road network
- 16 bioenergy and paper manufacturing

Figure 1 c. Structural analysis of key factors for objects in the Republic of Karelia

Factor colors: yellow - economic, green - environmental, red - social, blue - political, white - technological

The results of the research revealed that the key factors at all sites included a regulations framework containing generally binding rules for the use, safety, protection, and reproduction of forests, interaction schemes for the use of forest plots, as well as forest planning, which determines the goal setting in forest management. For objects in the Republic of Karelia and in the Nizhny Novgorod Region, the factor «monopolization of forest management by state authorities, bureaucratization» has been identified, which characterizes the limitation of the possibility of making managerial decisions by regional and municipal authorities, the transfer of powers to federal authorities. Since Russia has an absolute monopoly of state ownership of forests, the economic mechanism of forestry is under the directive influence of political state institutions. The political system largely determines the organization of planning, the legal status of the subject and the object of planning. In this regard, a group of «regulation» factors has been identified in a framework direction that affects all other factors and, at the same time, is subject to their influence only if legislative initiatives are available and appropriate mechanisms for their implementation are developed. When developing scenarios, the influence of political institutions was taken according to the current situation.

A structural analysis of the identified key factors showed that for objects in the Nizhny Novgorod Region and the Republic of Karelia (Fig. 1a, c), environmental instability factors that simultaneously have high passivity and activity were mainly economic factors: «wood market», «bioenergy, paper, and pulp market», «forest tourism market, including hunting». The factor «protection of species and ecosystem functions» was also attributed to them. The first two factors, the «wood market» and the «bioenergy, paper and pulp market», characterize the demand for forest energy – wood supply in general, therefore, they were combined in the direction of «Wood supply». The first group of factors characterizes the strength/ importance of economic relations arising from the purchase and sale of wood on the root and products from it.

The factors «forest tourism market, including hunting» and «protection of species and ecosystem functions» show the value of the forest as a provider of environmental (regulating, supportive) and cultural resources, conservator and supplier of biodiversity. Biodiversity directly affects the attractiveness of a forest area for recreation and provides a wide range of hunting resources. The protection of biodiversity today is also the only mechanism for regulating the provision of non-monetary ecological forest resources. Based on the idea that these key factors depend on the extent to which the protection of biodiversity is the focus of forest management, they were grouped into the «Environmental protection» direction.

For an object in the Moscow Region (Fig. 1b), environmental instability factors are more social in nature. Such factors as the «forest tourism market», «construction on forest fund lands», and «recreation of the population» are based on human needs in «communication» with nature, in rest from urban life, therefore they were combined in the direction of «Recreation». This direction reflects the importance of the forest area for the provision of cultural services for recreation and tourism in the forest. The second direction is formed by combining the factors «protection of water and air» and «protection of species, their habitats, and ecosystem functions». Its name is consonant with the directions of other objects of research «Environmental protection» and is dictated by the same unifying principle of biodiversity conservation.

Political scenarios. For forest plots in the Nizhny Novgorod Region (Fig. 2), the combination of extreme values of such areas as «Wood supply» and «Environmental protection» allowed the development of four policy scenarios. The first one characterizes the current situation at the research site. This scenario is characterized by the high importance of the forest as a source of wood and the lower importance of maintaining biodiversity and protecting the environment in general. The main goal of forest management in this scenario is to maximize profits from logging while minimizing environmental protection costs. The second scenario is conventionally named «Multipurpose forest use via segregation». It describes a situation where both directions are not a priority. Here, forest management is aimed at making a profit from the forest in conditions of reduced demand for wood, while reforestation is also not the goal of forest management. Making a profit from a forest plot in the circumstances is possible due to its use for recreation, tourism, and for harvesting food forest resources. A combination of these types of forest use in one territory is possible when zoning the territory, where recreational routes will be allocated, within which the collection of food forest resources is possible for recreation, and zones for the industrial collection of mushrooms and berries. The third scenario arises when biodiversity is recognized as a key value in forest management. The profit from the forest area is redirected from logging to regulating forest resources, for example, carbon deposition, regulation of the water regime, or the formation of soil fertility. Currently, there are no mechanisms for obtaining benefits from ecological ES of forests, but it is assumed that in the future there will be a development of ES markets that will ensure the plausibility of this scenario. A striking example is the development of carbon markets. The fourth scenario, «Bioeconomy», describes a situation where the value of forests as a source of wood is as high as the value of environmental protection. This scenario assumes that in order to meet the demand for wood, which is used to replace carbon-intensive products, while preserving biodiversity, first, the development of methods for deep processing of wood biomass will occur, and second, the intensification of reforestation.

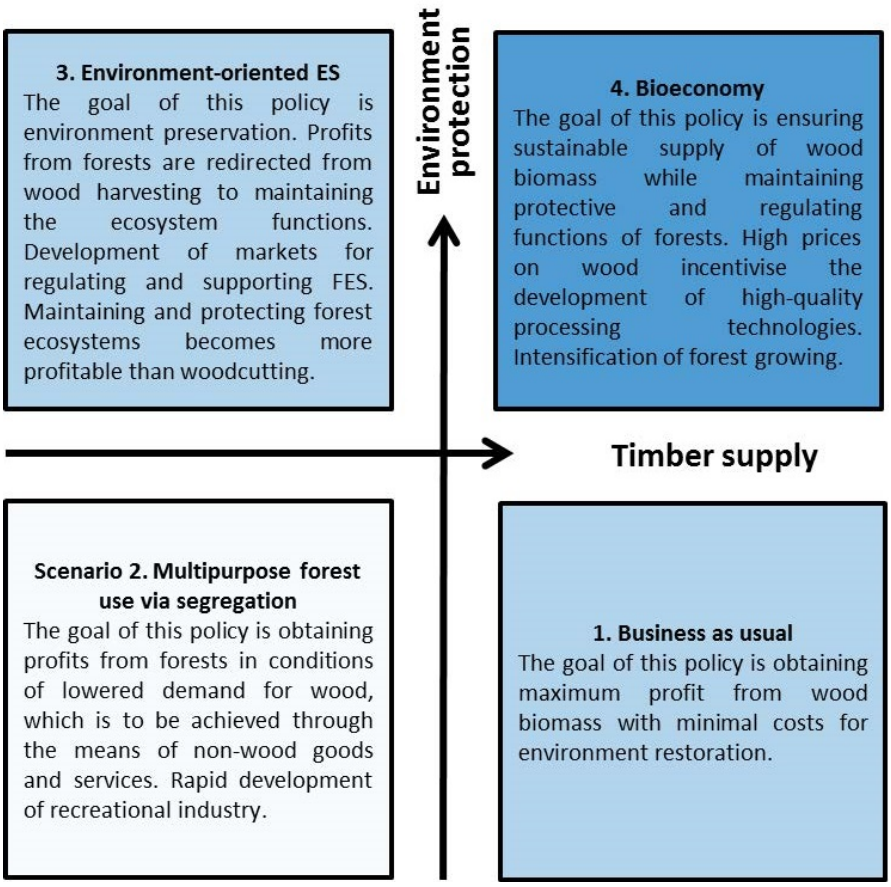


Figure 2. A matrix of scenarios for an object in the Nizhny Novgorod Region

For forest plots in the Republic of Karelia (Fig. 3), when discussing the direction of «Wood supply», it was found that its extreme values meant that the demand for forest biomass would either remain at the present level (negative values of the abscissa axis) or would increase (positive values of the abscissa axis). In this case, the «Business as usual» scenario corresponds to a situation where the demand for wood remains consistently high, while ensuring environmental protection. The conservation of biodiversity in this case is not so much the result of legislative measures, but rather the result of the low availability of forest areas for timber harvesting and the lack of road infrastructure. Here, the cultural and regulating FES are an encumbrance. Precisely because of the lack of a road network, a scenario where the demand for wood does not change (is consistently high) and the value of environmental protection decreases is considered impossible since the anthropogenic disturbance of ecosys-tems requires the presence of roads, the volume of construction of which is predicted to be insig-nificant at the current level of demand for wood.

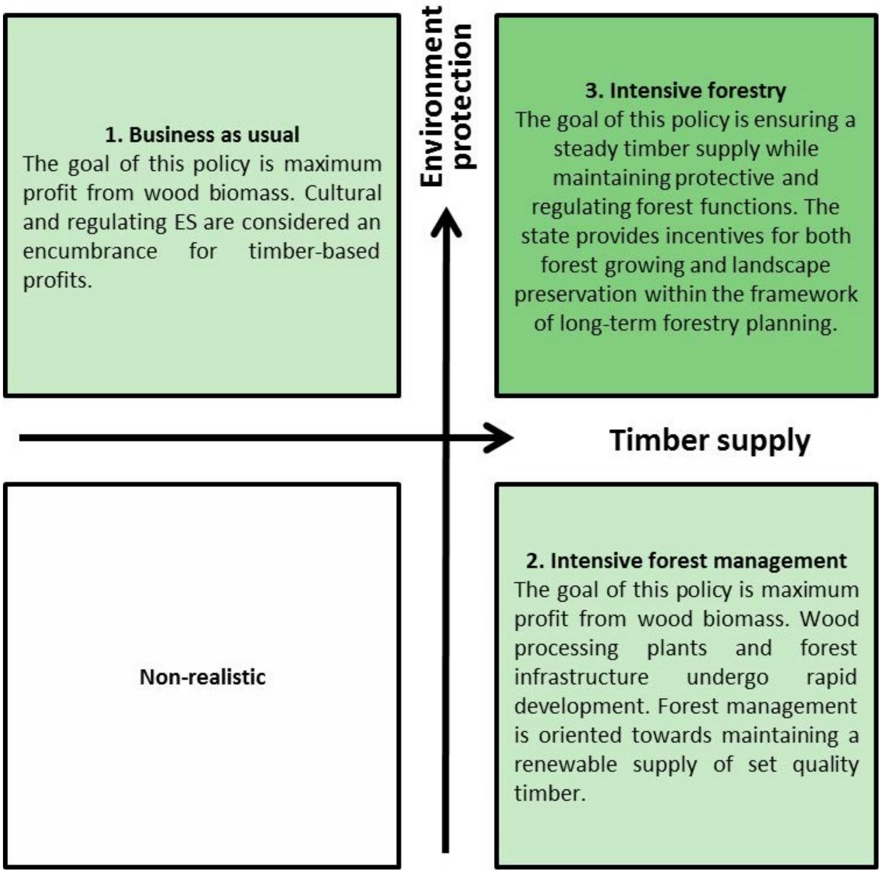


Figure 3. A matrix of scenarios for an object in the Republic of Karelia

The other two scenarios – «Intensive forest management» and «Intensive forestry» – are characterized by increased demand for wood, which stimulates the construction of road infrastructure. The policy objective of the first scenario is to maximize profits from woody biomass; the second scenario is to meet the demand for wood, provided that the protective and regulating ES of forests are preserved. Unlike an object in the Nizhny Novgorod Region with similar directions, achieving the goal of the «Intensive forestry» scenario is possible without zoning using forestry measures, since this object is located in a remote area where population density is low and there is no need for zoning of the territory.

Experts considered two out of four scenarios unrealistic for forest plots in the Moscow Region (Fig. 4). These are scenarios, in the development of which it is assumed that the need of citizens for outdoor recreation will be insignificant or will remain at the same level (negative values of the abscissa axis). The value of the forests of the Moscow Region for the satisfaction of citizens in the cultural ES of forests, in particular, recreation, is constantly growing due to the influx of population to this region, therefore, the direction of «recreation» is a steady trend, and it is predicted that its value will only grow in the next hundred years. Thus, two scenarios are relevant for an object in the Moscow Region: the «Business as usual» and «Multipurpose forest use via segregation». The «Business as usual» scenario is characterized by a trend of increasing the value of forests for recreation of the population and the low importance of biodiversity conservation and environmental protection. Urbanization processes stimulate the development of the recreational infrastructure of the territory; the local population actively and spontaneously uses the forest area for recreation. Thus, the natural landscape is transformed into an anthropogenic, disturbed one. The policy objective in the second scenario «Multipurpose forest use via segregation» is to achieve a balance between regulating and recreational forest resources. The goal setting is dictated by the need, on the one hand, to provide citizens with recreation places in the forest, on the other, by caring for the preservation of the forest ecosystem in order to perform sanitary, hygienic, water protection, and protective activities. The achievement of the goal is possible with the zoning of the forest area with the implementation of appropriate forestry measures for the purpose of the zone.

Forestry scenarios. Forestry scenarios are sets of input parameters for modelling trade-offs and synergies between FES using the RUFOSS software package (RUFOSS, 2020). Simulated forestry regimes include: 1) zoning of the territory; 2) felling of ripe and overgrown forest stands; 3) logging for care; 4) cleaning of felling residues, dead wood, and litter; 5) reforestation; 6) other types of forestry activities. The purpose of logging takes place annually and continuously; the permissible allowable cutting rate is calculated for one year, and then for a modelling step (5 years).

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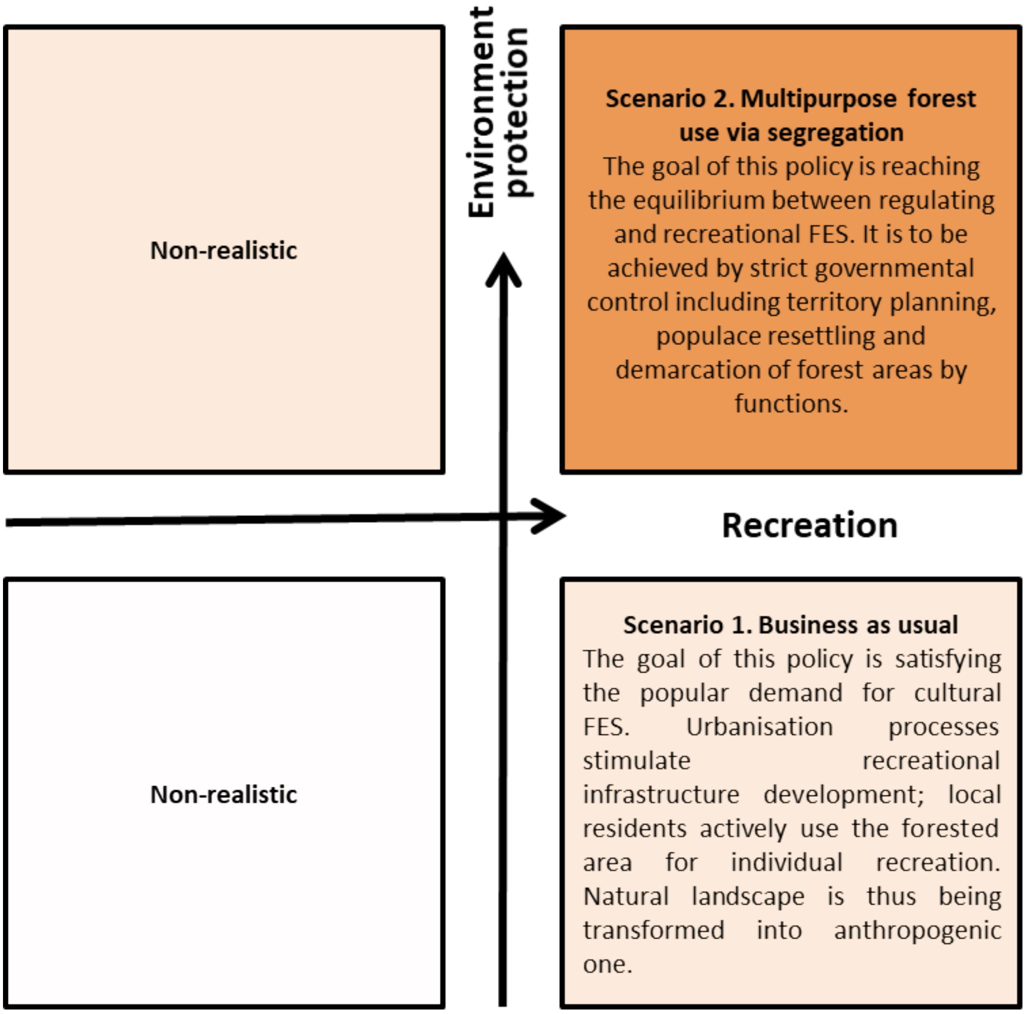

Figure 4. A matrix of scenarios for an object in the Moscow Region

For an object in the Nizhny Novgorod Region, for the «Business as usual» scenario, forestry measures are carried out in accordance with the established practice. The distribution of forests for their intended purpose corresponds to the present boundaries. In operational forests, clear cutting of plantations that have reached the age of ripeness is carried out, in protective forests, two-stage voluntary selective logging is carried out; at the same time the allowable cutting rate is being utilised up to 87%. Felling residues are removed from the cutting area. The ratio of artificial and natural reforestation is 60:40. Logging of forest maintenance is carried out in accordance with the forest development project in order to form pine and spruce plantations; their implementation is 79% of the permitted volume under the forest development project.

In contrast to the «Business as usual» scenario, in the «Bioeconomy» scenario, the utilisation of the allowable cutting rate together with thinnings reaches 95% of the volumes stipulated in the Forest Development Project. In operational forests, artificial reforestation is carried out; in protective forests, cutting areas are left for natural overgrowth. The abandonment of cutting areas for natural regrowth is dictated by the idea of preserving biodiversity and the formation of multi-age, polydominant forest plantations that better fulfil the regulating ES (regulation of the water regime, cycles of nutrients and carbon) of forests, in contrast to monodominant single-age forest crops. At the same time, the planting of forest crops is necessary to meet the demand for wood; therefore, artificial reforestation is carried out in operational forests.

Based on the idea of environmental protection, in the «Environment-oriented FES» scenario, all protective forests are decommissioned, and a protected regime is established in them. On the territory of operational forests, logging of ripe and overgrown forest stands is carried out only in the form of voluntary selective logging (95% development of the allowable felling rate) followed by natural regrowth on clearings. At the same time, the entire cycle of logging is carried out in full. Felling residues remain in the cutting area to form habitats for biota.

For the scenario «Multipurpose Forest use via segregation», zoning of the territory was carried out. It is worth noting that the assigned forestry measures are estimated. As a result of modelling, they need to be adjusted.

The zoning is based on a survey of the tenant of the forest area and local residents, who indicated the route of horseback riding, rafting on the Vetluga River, tourist sites, as well as allotments visited for the purpose of picking mushrooms and berries. Thus, five zones are allocated. The first two zones are located in operational forests: (1) An area has been allocated for horseback riding (equestrian route). Forestry activities in this area are aimed at creating an attractive landscape for forest recreation. However, taking into account that this territory is not a green zone, while planning forestry activities the authors did not adhere to principles of recreational landscaping. On the contrary, it was assumed that the attractiveness of the landscape for tourists would lie in its naturalness, besides, during a horseback ride, tourists can stop to collect mushrooms since the equestrian route coincides with the places where mushrooms are collected. Therefore, it is planned to carry out selective logging to the density of 0.5 at the first stage. The utilisation of the allowable cutting rate is 87%. When carrying out logging, the density of 0.7 was considered optimal for the growth of mushrooms and for the visibility of the plantation. Logging is carried out in full, reforestation is natural. (2) The operating area is intended for harvesting wood. Clear cuttings are being performed there, followed by artificial reforestation. The utilisation of the allowable cutting rate is 95%. Logging operations are carried out on 79% of the planned territory. The next three zones are located in protective forests. (3) The territory for harvesting berries is allocated in the central part of the forest area. Cranberry places are located here. Two-stage voluntary selective logging is carried out, followed by natural overgrowth and a full cycle of forest care. The utilisation of the allowable cutting rate is 87%. (4) In the mushroom harvesting area, forestry measures are aimed at increasing the yield of mushrooms. Three-stage voluntary selective logging is carried out, where at the first stage the density is reduced to 0.7, and at the second – to 0.5. The target species are pine and spruce. Cutting areas are left for natural overgrowth, but logging is carried out (5). A complex of forestry measures is carried out in protective forests, as for the berry harvesting zone, but here the utilisation of the allowable cutting rate reaches 95%. Special protection areas were not included in the zoning. The forest management regime for them in each scenario remains in accordance with the current legislation.

For forest plots in the Republic of Karelia, for all scenarios, the location of protective and operational forests remains unchanged and corresponds to the current division. In protective forests, two-stage voluntary selective logging is carried out, in operational forests – continuous logging, but in the case of the «Business as usual» scenario, the percentage of development of the allowable felling rate is less than in the other two scenarios: 65% vs. 90%. It was decided that 100% development was impossible due to natural barriers to road construction and forestry restrictions, such as the timing of the connection of cutting areas, the number of cuts, therefore, the maximum percentage of utilisation of the allowable cutting rate was 90%. Unlike the «Business as usual» scenario, in other scenarios as well, the volume of logging is 35% higher, while in the «Intensive forestry» scenario, not only coniferous but also small-leaved species are the target species for maintaining biodiversity. To preserve habitats, felling remnants remain in the cutting area as well. In order to meet the demand for wood, the share of artificial reforestation in the «Intensive forest management» scenario is 17% higher than in other scenarios.

The «Business as usual» scenario in the Moscow Region corresponds to a forestry scenario, in the development of which two-stage voluntary selective logging is carried out followed by natural overgrowth, and a full cycle of logging is carried out with a focus on growing coniferous species. Sanitary logging is typical for this region, but the technical capabilities of the RUFOSS mathematical model integration module do not imply the possibility of modelling sanitary logging. Therefore, sanitary loggings were replaced by voluntary selective ones. For the scenario «Multipurpose forest use via segregation», the zoning of the territory was carried out. The current situation regarding the recreational use of the site by the population became the basis for the allocation of zones. Thus, (1) an active recreation area has been allocated. Here, the formation of stable, aesthetically valuable plantations of a forest park character is carried out by carrying out logging with an orientation towards the cultivation of oak and pine. Undergrowth care and selective logging with harvesting of felling residues and dead wood are carried out. The clearings are left for natural regrowth. (2) In the walking area, woodland park stands, complex in composition and shape, are formed. Selective logging is carried out to form open and closed spaces with the cleaning of felling residues and dead wood. Thinning is being carried out regularly with an overall focus on the cultivation of pine and oak. The order of sampling of trees Aspen-Spruce-Birch-Linden-Maple; care of the undergrowth is not carried out. (3) The faunal rest zone is allocated on the basis of the passport of the natural monument «Pine forest with trefoil cress» (Passport for the natural monument of the Executive Committee of the Moscow Regional Council of People's Deputies dated June 29, 1984 No. b/n) and the boundaries of the projected reserve «Mixed-deciduous forests by the Sushka River». Forestry activities are not carried out in this area. (4) The forestry zone is allocated in the least visited forest areas. Forest recreation is possible here. Forestry activities in this area are similar to those in the «Business as usual» scenario.

Thus, for three objects located in different climatic, economic, and social conditions, political and corresponding forestry scenarios are justified, which can be used to predict the dynamics of FES, compromises and synergies between them in order to make effective management decisions. The «Business as usual» scenario acts as a control for all scenarios. At the same time, it is recommended to keep in mind the second control – the scenario of natural development of forest plantations, excluding any forestry intervention.

Comparison of the INTEGRAL and POLYFORES methods. The approach to the construction of forestry management scenarios implemented within the framework of the POLYFORES project is partially based on the approach developed and used in the INTEGRAL research project. Both of these approaches ensure the development of the same type of scenarios – research and normative, using qualitative and quantitative methods. Compared to the INTEGRAL methodology, the approach to building scenarios in POLYFORES is simpler and clearer. For example, INTEGRAL scenarios corresponding to POLYFORES political scenarios are also given in the form of descriptions, but are constructed using quantitative methods and software. The analysis of the coherence of the manifestations of elements in the INTEGRAL method shows the consistency of manifestations, not stability. Despite the fact that the manifestations themselves will be effective during the selected time range, there is no guarantee that the combination of these manifestations will also be stable over this period. Using the INTEGRAL method, it is possible to obtain an unlimited number of scenarios, although it is generally assumed that 3–5 scenarios are the optimal number for analysing the future development of the territory (Amer et al., 2013).

Therefore, researchers are faced with the need for an additional step in scenario development – clustering of coherent combinations, in order to reduce the set of scenarios.

However, the most important difference between POLYFORES and INTEGRAL is the greater flexibility and the presence of a creative component of the POLYFORES method, which makes it possible to take into account trade-offs and synergies between factors or the possibility of new key factors. It is possible to capture such phenomena using methods based on stimulating the creative activity of stakeholders, but so far there is no software capable of detecting them.

The weak link of both methods can be called the transition from a qualitative description of the storylines of scenarios to their quantitative aspects. Using the POLYFORES project method, an appropriate forestry scenario has been developed for each policy scenario, but there may be more forestry scenarios, so it is recommended to use forestry scenarios as a starting point for approving a forest use plan.

Forestry scenarios are not just possible, but need to be adjusted depending on the results obtained during simulation.

CONCLUSION

The results of the study revealed three methods of scenario development for the simulation of FES: the principle of the cross-matrix, morphological analysis, and the construction of a tree of events. All of them make it possible to construct qualitative scenarios and are based on the identification of key factors and the analysis of their probabilistic manifestations. The choice of the principle for constructing scenarios depends on the set research goal, the number of identified drivers, and the analysis budget. Morphological analysis is the basis of a widespread method developed within the framework of the INTEGRAL project. In contrast to this method, the method proposed within the framework of the POLYFORES project is based on the principle of a cross-matrix, which makes it possible to significantly simplify the process of scripting by eliminating the need to use software for data processing, obtaining a limited and sufficient number of scenarios for modelling the future. Finally, due to the greater creative component this method makes it possible to take into account trade-offs and synergies between key factors that may lead to the emergence of new factors in the future.

The approbation of the new method within the framework of three case studies has shown its viability. Thus, four scenarios for the development of a forest area have been developed for forest areas in the Nizhny Novgorod Region. The first scenario involves obtaining benefits from logging, the second –

from recreational ES and food forest resources, while using zoning of the forest area, the third – from regulating FES, and the fourth – both from logging, subject to intensification of forest cultivation, and from regulating ES. Three scenarios have been developed for forest areas in the Republic of Karelia. The first scenario describes the situation of meeting the demand for wood, provided that biodiversity is preserved and forests are regulated, the second and third scenarios are characterized by increased demand for wood, low, and high priority for environmental conservation, respectively. Two scenarios are relevant for the forest areas of the Moscow Region, in which the need of citizens for recreational FES will increase, and the priority of biodiversity conservation in making management decisions will either remain low or increase.

For forest plots located in the Republic of Karelia and in the Moscow Region, several scenarios were considered unrealistic. It is worth noting that brainstorming, group discussion, and expert group interviews were used to identify key factors and develop scenarios for these objects, while a specialized seminar was held for forest sites in the Nizhny Novgorod Region, where all scenarios were recognized as realistic. Combining the knowledge of local stakeholders and the scientific community makes it possible to obtain realistic, more detailed, meaningful, and relevant ideas about the possible future dynamics of the socio-ecological system.

The conducted research contributes to the formation of scientific and methodological foundations of the management decision support system, to the creation of a scientific basis for the development of new technologies and techniques in the field of forecasting the dynamics of the ecological and resource potential of Russian forests, sustainable use of forest resources and ecosystem services, conservation and restoration of biodiversity.

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РАЗРАБОТКА СЦЕНАРИЕВ ДЛЯ ИМИТАЦИОННОГО МОДЕЛИРОВАНИЯ ЭКОСИСТЕМНЫХ УСЛУГ ЛЕСОВ

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Устойчивое управление лесами предполагает необходимость сохранения и обеспечения баланса между растущим спросом на экосистемные услуги (ЭУ) лесов и имеющимися возможностями. Эта проблема мотивирует разработку путей включения разнообразных ЭУ в систему планирования и управления лесными экосистемами с учетом социальных, политических, экологических и экономических контекстов. Одним из эффективных инструментов управления ЭУ является имитационное моделирование, позволяющее оценить риски и последствия принятия решений. При этом возникает научная задача обоснования возможных альтернативных сценариев развития будущего лесной территории для последующего имитационного моделирования.

Настоящая статья нацелена на анализ подходов к разработке сценариев развития лесной территории для имитационного моделирования локального уровня и на апробацию нового метода, основанного на развитии существующих подходов к решению этой задачи. В первой ее части дан анализ современных исследований в области разработки имитационных сценариев; во второй предложен новый метод составления сценариев, сформированный в рамках проекта POLYFORES, а также приведены результаты его апробации на трех модельных объектах, расположенных в Нижегородской области, Республике Карелия и Московской области. Для лесных участков Нижегородской области разработано четыре сценария развития лесного участка с целью получения выгод: 1 – от заготовки древесины, 2 – от рекреационных ЭУ и пищевых лесных ресурсов, 3 – от регулирующих ЭУ, 4 – как от заготовки древесины, при условии интенсификации лесовыращивания, так и от регулирующих ЭУ. Для лесных участков в Республике Карелия первый сценарий описывает ситуацию удовлетворения спроса на древесину при условии сохранения биоразнообразия и регулирующих ЭУ, второй и третий сценарии учитывают повышенный спрос на древесину, низкий и высокий приоритеты по сохранению окружающей среды. Для лесных участков Московской области актуальны два сценария, при которых потребность граждан в рекреационных ЭУ увеличится, а приоритет сохранения биоразнообразия при принятии управленческих решений или останется низким или увеличится. Для каждого сценария разработаны соответствующие целям управления лесохозяйственные мероприятия. Предложенные сценарии могут быть использованы для получения информации о влиянии различных управленческих решений на предоставление лесных ЭУ.

Ключевые слова: *сценарий, экосистемные услуги лесов, ключевые факторы, лесохозяйственные режимы, Европейская часть России*

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