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Approaches to the Assessment of the Natural Capital of Forests and the Prospects for Modernization of Forest Management in the Context of Green Economy

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Abstract. The goal of the paper is to study approaches to the assessment of natural capital of forests, especially forest resources, and the prospects for modernization of forest management in the context of green economy. We show that current socio-economic development strategies in most countries encourage rapid accumulation of physical, financial and human capital through excessive depletion and degradation of natural capital, which includes natural resources and ecosystems. In order to prevent this threat, it is necessary to move to the concept of green economy that involves effective use of natural resources, ensuring the sustainability of natural ecosystems and reducing the use of resources in production and consumption. In this regard, we study indicators and methodological approaches used for measuring and assessing forest resources in the global and domestic practice. We reveal the shortcomings and limitations of their application, which are associated with the quantitative assessment of the state of

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forests, without taking into account qualitative and structural changes. On this basis, we develop our own original methodology for assessing forest resources and in the future – assessing their depletion on the basis of comparing the current state with the "reference" state. An important point in this technique is the account of fragmentation in the assessment of forest resources, implemented through the analysis of spatial distribution of the sections of raw materials bases. The results of our assessment confirm a significant depletion of forest resources throughout the Komi Republic. In order to restore and preserve them, we substantiate the combined use of three basic directions: forest management activities corresponding to the potential of reforestation; rehabilitation modernization of forest management, involving the organization of forest management in the form of recurrent cycle of selective cutting; and compensatory strategies of timber processing. The prospects for further research are related to the task of developing a model for the use of forest resources in the region, ensuring the sustainability of supply of timber processing industries with raw wood.

Key words: natural capital of forests, forest resources, forest management, modernization, green economy.

Introduction

The natural capital of forests in a broad sense includes not only forest (primarily wood) resources, but also the whole range of ecosystem services related to a healthy environment, the quality of water ecosystems, the opportunities of using non-wood forest products, as well as recreation and aesthetic and spiritual values of nature. This approach is reflected in many publications by foreign (R. Contanza, D. Alkamo, etc.) and domestic researchers (S.V. Bobylev, I.P. Glazyrina, G.D. Titova, D.E. Konyushkov et al.) [1–7].

Therefore, when we talk about the natural capital of forests and its preservation we emphasize not only its economic component but also its environmental and social value for the population of traditional "forest" regions of Russia, in particular the Komi Republic. This approach underlies the global trend towards economic "greening" in order to ensure the long-term sustainability of natural ecosystems and prevent their degradation [8].

The concept of "green" economy involves efficient use of natural resources, ensuring the sustainability of natural ecosystems and reducing the use of resources in production and consumption (resource efficiency). In the late 1980s–early 1990s, when considering the approaches to the "green" economy the leading Western researchers [9, 10, 11] paid attention to preservation of natural forest capital for future generations. Preserving the natural capital of forests based on the principles of "green" economy is fundamental for ensuring the long-term sustainability of the entire forest sector of economy.

The wish to assess the state of forest resources and propose approaches to their measurement, conservation and sustainable use is reflected in the documents of international organizations. One of them is the Rovaniemi Action Plan for the forest sector adopted by the UNECE and FAO in 2013. The document affects 56 countries in Europe, the Caucasus, Central Asia, and North America [12]. The main lines of this Plan implies rational use of forest resources, minimization of waste, and maximum possible reuse (recovery); replacement of non-renewable materials and fuels with renewable materials and wood fuels; supply of goods and services with great value to their consumers.

Developed OECD member states see the main objective of the forest sector in providing the required volume of wood of appropriate quality with optimal cutting standards that preserve forest capability.

When implementing the Declaration on Green Growth (2009) OECD countries called for the promotion of economic growth and development to preserve national wealth. "The main problem is the anthropogenic load affecting the natural growth and restoration of forests and its impact on the economic, environmental, and social functions of the forest. Anthropogenic load includes the unsustainable exploitation of forest lands, their segmentation, degradation of environmental quality of forests, deforestation ..." [13, p. 89]. OECD forest indicators include timber resources and forest areas; the depletion of forest resources can be assessed indirectly using the indicator of forest resource exploitation calculated as a ratio of felling volume to gross growth, which roughly corresponds to domestic utilization of calculated felling rate.

An important global document regulating the preservation of natural capital is the 2030 Agenda for Sustainable Development [14]. One of the 17 sustainable development goals (SDG–15) focuses on protection and restoration of terrestrial ecosystems and promotion of their sustainable use and sustainable forest management. The preservation of natural capital of forests as an economic resource is considered in Goal 15.1 which declares promotion of methods of rational use of all types of forests, restoration of degraded forests and a significant expansion of forest restoration, action against deforestation and forest degradation. The indicators of its implementation are the areas of certified forests and intact forest landscape which need to be doubled by 2030.

Countries' global studies on "green" economy of the forest sector demonstrate that Russia is in a relatively favorable situation. The environmental impact of economic activity on natural ecosystems is 30–40% lower compared to EU member states, which is explained by higher bio-intensity, while the global consumption of resources is 1.5 times higher than the planet's ability to restore them [15].

In order to assess sustainability at the level of macro-regions the ECE Committee on Forests and the Forest Industry (COFFI) together with the European Forestry Commission (EFC) established by FAO developed a System for the Evaluation of the Management of Forests (SEMAFOR) [16] which includes 20 evaluation, 27 contextual and 5 reference parameters. In order to preserve the natural capital of forests it is proposed to take into account the resources per hectare and the area of forests suitable for timber harvesting by quality characteristics.

Forest indicators included in reviewed and other international policy documents reflect the green course of the forest economy and can be used for regional studies. It is important to take into account that general characteristics of wood resources and forest areas in relatively forest-sufficient regions, which include the Komi Republic, will not give an accurate idea about forest resources. At the same time, specific SEMAFOR indicators can be applied for the development of new tools to assess forest resources and their application structure in production and consumption [17].

Thus, the purpose of the present paper is to study approaches to assessing forest resources and prospects for modernizing forest management in the context of the global trend in economic "greening".

Approaches to assessing natural capital of forests at the national and local system level

Basic indicators of forest resources are widely used to compare countries by level of development. These include: area of land covered with forest (thousand ha), area of forest land (thousand ha); forest cover – the ratio of area covered with forest to the total country's or region's area, %; protected areas (thousand ha); age structure of forest land (mature, overmature, etc.); distribution of forest

resources according to the pedigree structure (coniferous, deciduous); total wood reserve (including mature and overmature species), thousand m^3.

However, these indicators, being able to reflect the quantitative state of forests, do not assess their qualitative and structural changes. In the past 20–30 years, developed countries have begun to develop methods to directly or indirectly assess the degradation of forest ecosystems (forest depletion). The emphasis is put on aggregates based on many data that can be used to judge the degree of resource and environmental sustainability of the socio-economic development.

Examples of this approach include the following methods:

– net present value (NPV) proposed by the World Bank. It assesses capital as a value that generates income over time, except for the value of protected areas [18];

– economic assessment of natural resources and negative impact on the environment in the system of environmental and economic accounting, where environment is considered as a reserved natural capital, and its anthropogenic use – as services provided by this capital [19];

– Index of Sustainable Economic Welfare – ISEW [20]. Here, the depletion of natural resources is measured as the amount of investment needed to create a resource equivalent;

– measuring environmentally sustainable national income – eSNI [21] defined as the maximum achievable level of production, in which environmental functions are maintained at the expense of technological development of the society.

In general, Western authors' methods for assessing the rational use of forest resources pay more attention to environmental risks, often leaving out the economic component of forestry and forest management. The disadvantages of these approaches in terms of application for the Komi Republic include a very large amount of necessary and inaccessible (especially cost) information for calculating indicators. The advantage of the approaches is the methodological focus not only on preserving natural capital, but also on restoring it to its initial state, which was the starting point for the development of the author's methodology for assessing forest depletion.

Domestic approaches to measuring natural capital of forests

The traditional approach to assessing the depletion of natural capital of forests in Russia is based on the size of the estimated felling rate which determines the allowable annual volume of timber removal in exploitable and shelter forests, providing a multi-purpose, rational, continuous, and sustainable forest utilization based on the established felling age. Under this scheme, it is conventionally believed that if the forest stand is cut down less than the annual estimated felling rate, such ecosystems are sustainable and, therefore, natural capital is preserved. These provisions are recorded both in normative documents [22] and in separate author's publications on this issue [23–25].

However, not all researchers believe that approaches to assessing forest depletion can be objectively evaluated using a traditional approach based on the calculated felling rate, so options for we offer options for its adjustment, taking into account additional indicators or factors. Such "adjusted" felling rate can be calculated using Formula 1 [26]:

$$V_{t+1} = V_t(1 + q) - Q - D, \qquad (1)$$

where V_{t+1} – a physical value of forest resources in a certain period of time (t +1), m^3;

q – natural growth rate of forest resources, m^3/year;

Q – amount of harvested wood in the period, m^3;

D – damage caused to forests, m^3.

To assess the "adjusted" felling rate to calculate the depletion or, vice versa, the increment of forest resources, additional indicators of damage caused to forests (from pests, fires, drying of plantations for a variety of reasons, etc.) are used.

Analysis of approaches to assessing natural capital demonstrates that their depletion is determined through the impact of mainly environmental factors, rather than structural changes in the composition of forest stand after cutting. However, Western approaches, unlike domestic ones, to some extent connect the assessment of natural capital with the efficiency of further processing in the chain of "harvesting–processing–consumption", while, as already noted, the efficiency of reforestation is at a high level.

Therefore, it is advisable to form two complementary approaches to the development of the national or regional forest industry in terms of preserving the natural capital of forests. The resource-based approach focuses on the conservation and restoration of forest ecosystems with estimating the level of forest depletion. The technological approach implies the assessment of natural capital by cost of the final product. At the same time, the efficiency of timber processing and output of products with high value added due to technological development is of fundamental importance. Both approaches are important and should be applied together. Enterprises modernize production facilities, generating value added of raw materials of smaller volume and worse quality, which preserves natural capital and compensates for its depletion. On the other hand, the state, as the owner of forests, through the forestry system ensures the preservation of productivity of forests, their species-quality characteristics through reforestation regulations and forest management regimes (harvesting rules, etc.).

Changing the potential of forest resources in the Komi Republic

In Russia, it is traditionally believed that the country has innumerable forest resources and that the objective of preserving and increasing forest capital is not relevant for us. Since the beginning of the 2000s, leading researchers, especially N.P. Chuprov, S.V. Pochinkov, A.P. Petrov, N.A. Moiseev and other experts in the forest sector and forestry, have written about the fact that inefficient forest management leads in particular to significant depletion of forests in traditional "forest" regions [27–32].

Let us single out a group of indicators of declining natural capital of forests:

1. Exhaustion of forest resources (quantitative): shortage of forest raw materials, especially lumber log; lower standing volume per hectare; decreasing economically accessible forest resources; continuous overcutting of forest resources in areas available for transportation (in areas of higher soil productivity, in areas suitable for summer harvesting, close to main consumers).

2. Exhaustion of forest resources (qualitative): change of species – pine, spruce, fir forests are replaced by birch, aspen forests, as well as coniferous monocultures of low productivity; segmentation of forest stands at felling; significant predominance of natural regeneration over artificial without subsequent timber stand improvement and lack of measures for future stand formation.

A key indicator of forest depletion is the performance of changes in average forest yield per hectare in developed forests, especially in coniferous forests. The Honored Forester of the Russian Federation, Professor V.F. Tsvetkov noted that the yield of forest stands in the Arkhangelsk Oblast and the Komi Republic decreased from 200–250 to 110–120 cubic meters per hectare [33] compared to the middle of the previous century.

The system of concentrated felling that has existed since the mid-1940s and is still being implemented with minor changes, has led to the fact that the concepts of "forest" and "forest resources" are no longer identical. This fact was pointed out in the early 2000s by well-known Swedish economists (Lars Karlsson et al.) who were dealing with forest management issues. Assessing the state of the Russian forest sector, they rightly noted that it does not have huge forest resources; the volume of forests is huge, yet it is not the same [34]. Such pessimistic estimates are explained by the fact that by maturity age forest stands differ significantly from first growth (virgin, "normal") forests in species and commodity structure.

The calculation of cost of forest depletion in the region carried out according to the developed original author's methodology, revealed negative trends that began with concentrated felling in the 1930–40s and still prevail (*Tab. 1*).

The data from the table help take into account the impact of negative trends:

– the range of hauling from the place of logging to lower standing significantly increased (now it is the main highway) due to the fact that available forests near traditional forest settlements are depleted and loggers "go deeper into the forest" to search for an acceptable quality of wood resources. The employment rate of people working in timber harvesting because they mostly work on a rotational basis, which reduces a city-forming role of settlements especially in rural areas;

– depletion of forests over the past 50–70 years has led to the fact that large and medium companies harvest timber on the periphery of the Komi Republic. Since the main centre of wood processing is located in Syktyvkar (pulp and paper, plywood and panel industry, wood-sawing), the hauling distance is increasing significantly; now contractor organizations harvest timber for OAO Mondi-SLPK (Syktyvkar timber processing complex) located 300–350 km away from the processing plant;

– all this leads to a significant increase in harvesting cost as transportation costs are increased and forest resources deteriorate because best resources are cut down and necessary forestry work on its reproduction is only carried out formally. The deteriorating quality of forest resources is illustrated by data on the reducing share of lumber log as the most valuable resource, which means a decrease in the weighted average price of round timber and a decreased profitability of logging.

Moreover, the current model of forestry development with a major processing centre does not increase the use of felling rate and, therefore, the felling volume because there is no additional sale for small wood and pulp wood. The deteriorating logging cost indicates the need for significant structural changes in the forest sector in the region.

Table 1. Calculation of forest depletion cost

Period	Lower standing hauling, km	Hauling distance, km	Hauling cost 3.5 RUB/m³ per km*	Share of lumber log, %	Weighted average price, RUB/м³*	City-forming role and impact on employment
1940s	Up to 10 km	50–100	350	Up to 60%	1600	Very significant
1980s	Up to 40 km	Up to 150	525	Up to 40%	1400	Significant
After 2000	Up to 80 km	150–200	700	15–25%	1200	Average
After 2015–2030	More than 100 km	Up to 300–350	1050	Up to 20%	1000	Not very significant

* Data on prices and costs are given in comparable prices. Calculated according to: data from the Forest Committee of the Komi Republic, Ministry for Investment, Industry and Transport of the Komi Republic.
Source: author's methodology.

Assessment of natural capital depletion in the forests of the Komi Republic

Based on methodological approaches and the current state of the forest complex of the Komi Republic economy, a methodology for assessing forest depletion has been developed which compares the current state of forest capital with the "reference" state of forests which could grow in natural conditions without human impact. Virgin or intact forests serve as a model for such a forest.

Forest resource depletion is defined as the difference between reference and actual forest (**ΔF**) according to the formula:

$$\Delta F = F(\text{reference}) - F(c), \qquad (2)$$

where ΔF – value of forest resource depletion; F(reference) – reference state of the forest; F(c) – the current state of forests (natural capital).

The reference state of forests was assessed for the Komi Republic based of expert assessments and data on typical conditions of intact forests in the northern and southern parts of the Republic. The main indicators of the quality of forest capital are: average volume of wood and assortment structure. Due to different natural and climatic conditions of forest growth, these indicators are differentiated by two zones (*Tab. 2*).

The parameters of the reference forest significantly exceed the actual indicators for raw materials supply of the Komi Republic, especially for sawn raw materials, the share of which in the assortment structure is on average 23–24%. Moreover, forest depletion led to a significant drop in the average supply per hectare, which in the Komi Republic (120–140 cubic meters according to various estimates) is lower than even benchmark indicators for forests in the North.

To assess the depletion of regional forest capital it is proposed to use natural and cost indicators characterizing the main parameters of forest resource quality – merchantability of stand, share of lumber log, and depletion of resources due to forest segmentation.

Physical indicators characterize: timber supply, its structure (assortment, species, and commodity structure), harvesting conditions (hauling distance to the consumer and/or to an all-weather road, level of forest segmentation (share of compartments exceeding the target indicator, for example, average stem volume on by raw materials supply). Cost indicators were used to determine merchantability of stand.

The information framework for assessing natural capital depletion of forests are data from the Forest Committee of the Komi Republic, the Komi Republic geoportal (on the quality of forests in the context of the net of rides), as well as the Federal State Statistics Service in the Komi Republic and Ministry for Investment, Industry and Transport of the Komi Republic (on the hauling distance, price of timber products). The assessment was carried out for raw material supplies distinguished when developing the General scheme of developing a network of forest roads in the Republic.

Results of merchantability assessment. The current state of natural capital is estimated through merchantability of stand, taking into

Table 2. Parameters of reference forest for the Northern and Southern zone of the Komi Republic

Forest zone	Average supply, m^3/ha	Assortment structure, %					Waste, %
		Coniferous lumber log	Coniferous roundwood	Leaf lumber log	Leaf roundwood	Fuelwood	
Reference (north)	160	45	30	5	6	6	8
Reference (south)	280	40	15	17	10	10	8

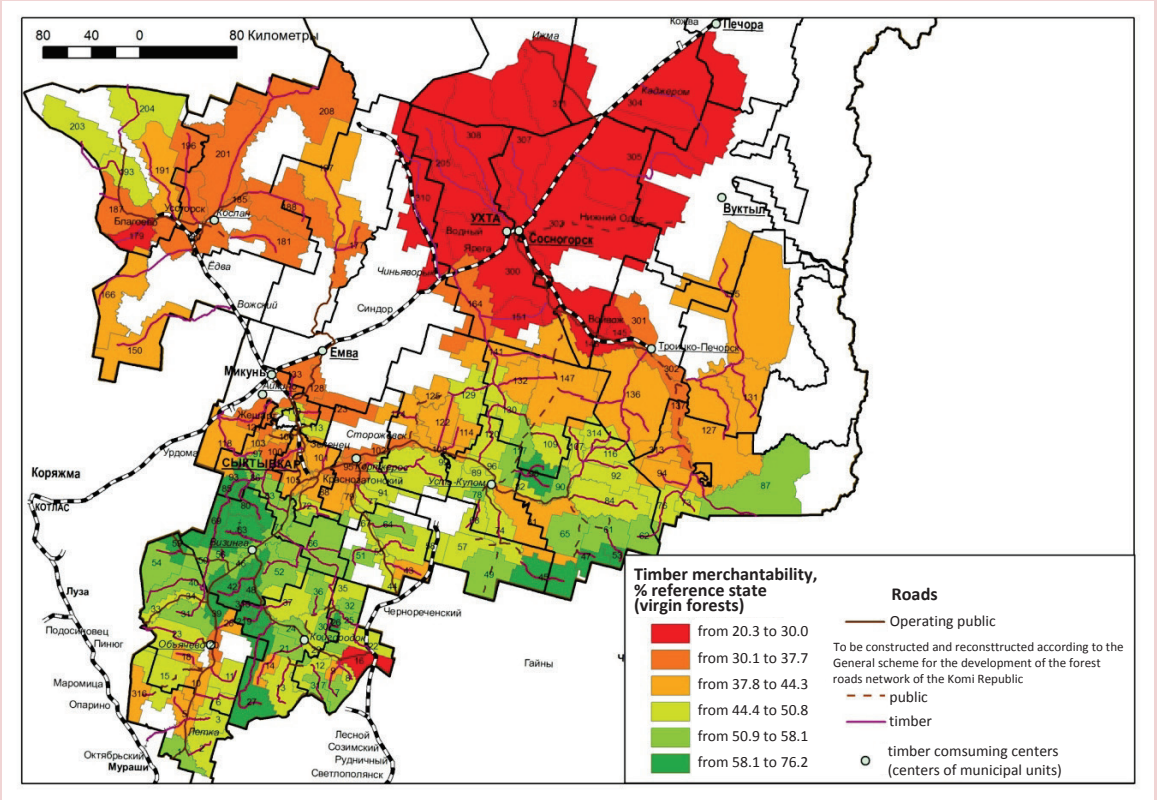
Source: author's methodology based on expert assessments of specialists of forestry universities of the Komi Republic, as well as data from the Forest Committee of the Komi Republic and Ministry for Investment, Industry and Transport of the Komi Republic

account both their structure and consumer value. The merchantability factor is calculated by multiplying the share of each element of the assortment structure of raw material supplies by the corresponding conditional cost of a cubic meter of this assortment. The unit value of assortment of round timber is defined as a ratio of its market value to the cost of fuelwood (the cheapest element of the structure). The merchantability indicator is adjusted by factor of supply per hectare, which is defined as a ratio of supply of a particular raw material to minimum supply for all raw materials. The final indicator of merchantability for determining the depletion is the product of factors of merchantability of a particular raw material supply and its supply factor.

To assess the depletion of natural capital in forests of the Komi Republic the indicators of merchantability for actual and reference forest are calculated. The ratio of these indicators shows the level of forest depletion (*Fig. 1*).

The level of real merchantability relative to the reference merchantability is inversely proportional to forest depletion. From data in the figure on a relatively high level of merchantability in the southern part of the Republic (from 44 to 76% of the reference value) we understand that the total forest depletion here comprises 25–55%. The situation is different in the northern part where levels of merchantability are low (20–44%) and levels of forest depletion are high – 50–80%. It is not by chance that in the northern

Figure 1. Merchantability of forest stand, % of the reference state



Source: calculated from data of the Forest Committee of the Komi Republic, Ministry for Investment, Industry and Transport of the Komi Republic, and the Komi Republic Geoportal. Map maker – V.A. Noskov.

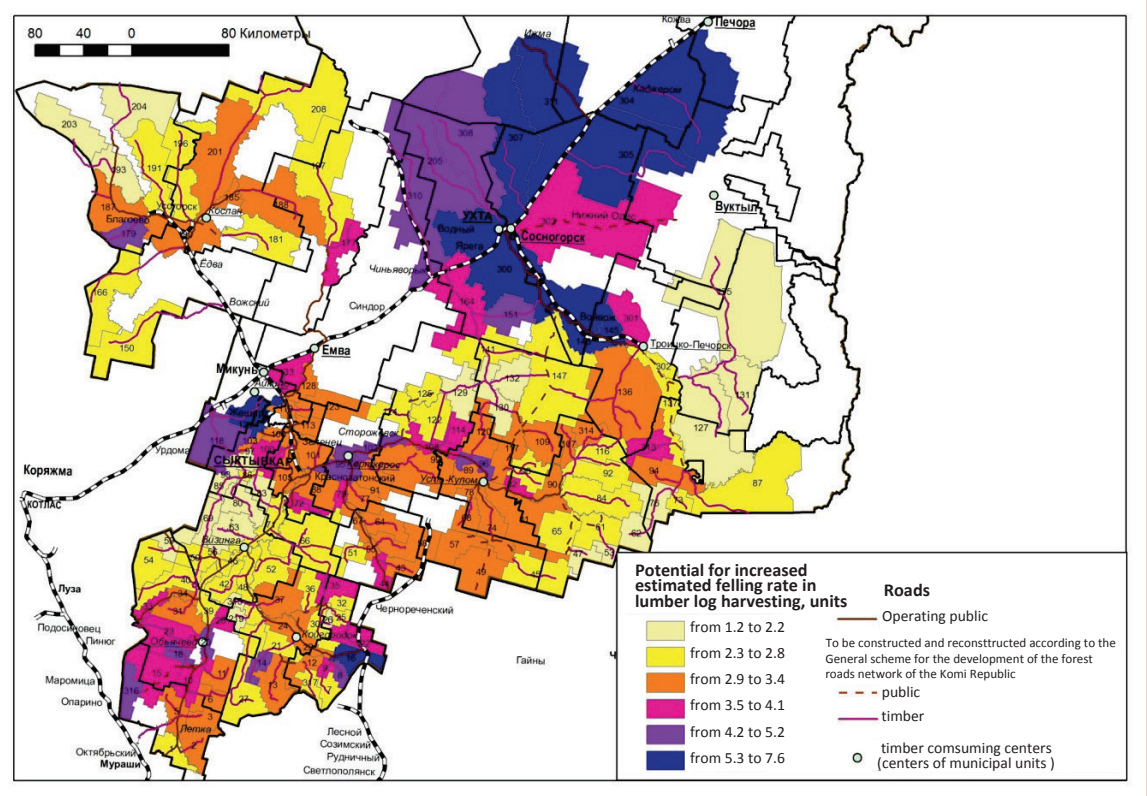
part there are many areas highlighted in white, where logging is practically not carried out due to significant forest depletion, which confirms the validity of calculations.

Results of assessing the quality of the assortment structure. In addition to general forest depletion, it is important to understand its depletion by key assortment of harvested timber – lumber log – the most valuable raw material for sawmilling and woodworking. The calculation is carried out through comparing the real and potential share of lumber log in the felling rate and demonstrates the excess of lumber log in the reference forest over the actual one (*Fig. 2*).

Analysis of the figure demonstrates that the depletion of the most valuable forests, especially for lumber log, is much higher than the average for stands, which is logical since loggers withdraw the most valuable merchantable wood from the forest – lumber log. The calculated total potential for increasing the estimated cutting area for lumber log was about 10 million cubic meters per year (while reducing the estimated cutting area for pulpwood), which is confirmed statistically.

Thus, the share of lumber log in the Komi Republic in the early 1980s, at the peak of timber harvesting in the amount of up to 25 million cubic meters, amounted to about 10–12 million cubic meters. Of course, the calculated value of increasing estimated cutting area for lumber log is a theoretical value and would be achievable with proper and adequate reforestation throughout the entire cutting cycle.

Figure 2. Potential increase in annual estimated cutting area for lumber log



Source: calculated from data of the Forest Committee of the Komi Republic, Ministry for Investment, Industry and Transport of the Komi Republic, and the Komi Republic Geoportal. Map maker – V.A. Noskov.

Results of evaluating the impact of segmentation on forest depletion.

Segmentation of forest stands after logging leads to violation of the spatial integrity of forests and formation of quite isolated forests. This problem is acute not only for our country, but also for the neighboring countries with developed methods of its assessment [35, 36].

Segmentation significantly affects the quality of forest resources, increasing their depletion. Moreover, it significantly increases the cost of logging due to the need for additional construction of hauling roads. The segmentation of forests does not help small and medium businesses select good forest areas for lease agreements because such areas are mainly leased by major loggers and are rarely located near highways.

To assess the segmentation of forests in the Komi Republic the average stem volume characterizing the quality of forest resources and maximum concentration of adjacent compartments were used as a characteristic of density if compartment groups with certain stem volume.

The assessment is carried out by raw material supplies identified when developing the General scheme of developing a network of forest roads in the Republic using the tools of the Komi Republic Geoportal which helps visualize the areas with the selected parameters on a compartment map. Since it is impossible to directly and automatically combine the net of rides at the website of the Geoportal and the map of raw materials, forest resource supplies with main types of woods in forest areas with considerable volume of logging were selected. These include resource supplies from the southern periphery (Letskoe forest area), southeastern periphery (Pruptskoe forest area), central (Kortkerosskoe forest area), northeastern (Troitsko-Pechorskoe forest area), and northwestern part (Udorskoe forest area). In order to assess the segmentation, we made a sample of compartments where the average stem volume is above average for the Republic (0.23 m). The assessment results are presented in *Table 3*.

The results of studying forest segmentation confirmed not only the general depletion of forests, but also the fact that the number of good dense forest areas is reducing. The best results are demonstrated in the southern periphery of the Komi Republic. For example, the Letskoe forest area formally possesses a large supply of wood with a great share of large timber – about 30–50% in specific supplies, but this is mostly wood from deciduous trees for pulp wood for pulp and paper. The presence of larger timber is also explained by better climatic conditions in the south, as well as by the total annual wood growth.

Forest resource supplies in the southeastern and eastern periphery are generally similar. In the Troitsko-Pechorskoe forest area, there are still separate good forestlands in a very large forest supply no. 321, where their share reaches a quarter, while they are quite dense. In the Pruptskoe forest area, intact forests still remain. These separate fragments are found only in hard-to-reach areas and are of interest only to major loggers and/or processors since road construction is required.

Forests of the western periphery are much more segmented, first of all, due to concentrated felling above estimated cutting area in the 1970–80s. In the Udorskoe forest area, forest depletion is much more noticeable. There are practically no untouched forests of high economic value, some fragments are found only in extremely remote places and are not of interest even for major loggers and/or processors.

In the central part of the Komi Republic, almost all forests have been cut down. For example, in Kortkerosskoe forest area, some areas of timber forest are found in raw material supply no. 79, 91, but their density

Table 3. Segmentation of forests in the Komi Republic

No. of compartment	Forest area	Total compartments, units	Compartments with stem volume ≥ 0.23 m³		
			Total, units	Share in supply compartments, %	Maximum concentration of adjacent compartments, units
Southern periphery					
3	Letskoe	144	90	62.5	61
6	Letskoe	83	38	45.8	30
1	Letskoe	85	34	40.0	25
2	Letskoe	141	53	37.6	23
5	Letskoe	91	21	23.1	12
Southeastern periphery					
48	Pruptskoe	121	59	48.8	39
45	Pruptskoe	71	38	53.5	31
57	Pruptskoe	61	0	0.0	0
Eastern periphery					
136	Troitsko-Pechorskoe	321	81	25.2	51
301	Troitsko-Pechorskoe	56	7	12.5	5
145	Troitsko-Pechorskoe	31	0	0.0	0
302	Troitsko-Pechorskoe	34	0	0.0	0
Western periphery					
208	Udorskoe	135	20	14.8	15
188	Udorskoe	122	5	4.1	2
201	Udorskoe	207	4	1.9	1
196	Udorskoe	105	1	1.0	1
181	Udorskoe	182	0	0.0	0
185	Udorskoe	21	0	0.0	0
Central part					
91	Kortkerosskoe	67	4	6.0	3
79	Kortkerosskoe	24	1	4.2	1
77	Kortkerosskoe	69	0	0.0	0
88	Kortkerosskoe	81	0	0.0	0
95	Kortkerosskoe	211	0	0.0	0
123	Kortkerosskoe	59	0	0.0	0
Total sample		2522	456	18,1	300

Source: author's methodology based on data from the Forest Committee of the Komi Republic, Ministry for Investment, Industry and Transport of the Komi Republic, and the Komi Republic Geoportal.

is extremely low. Selective studies on specific supplies in the center of the Komi Republic, in particular, in Syktyvdinsky, Kortkerossky, Ust-Vymsky, Sysolsky, and Koygorodsky districts demonstrate extremely low density of high-quality raw material supplies: forest are severely depleted, specific timber forests can only be found on the periphery of these areas in small volumes.

Practically, this means that any large-scale sawmill will require either construction of additional hauling roads, which is extremely burdensome, or supply of lumber log from other areas. It is no accident that new investment projects to create timber processing facilities in the central part of the Komi Republic face the problems of raw material supply: OOO Lesozavod no. 1 in the Ust-Vymsky district works on imported raw materials. OOO Promtekh-invest lumber factory, which started operating in 2017 in the Sysolsky district, also faces the problem with lumber log supplies.

The result of forest segmentation in the Komi Republic is limited large supplies of highly productive forests. Forests have been cut repeatedly, which leads to the fact that even major logging companies have dozens of cutting areas within one calendar year to be able to harvest affordable wood of a required assortment structure.

Recovery model to preserve natural capital of forests and modernization lines for regional forest management

Modernization of the bio-resource economy in terms of preserving natural capital of forests is possible under several scenarios, in which amid current conditions priority is given to increasing the share and depth of wood processing in order to compensate for forest depletion. However, this scenario is limited in the medium term as it potentially reduces the volume of wood processing with the processing limits being critical, which shows the importance of the second scenario which preserves the initial quality of forests with a tendency to improve it.

Attention should be paid to the restoration model of forest management which uses forest management measures, including the transition to intensive forest management, which will help completely restructure the system of forest management and reforestation within a decade and get noticeable results in 20–25 years.

A good example is Finland with a fundamentally different approach to reforestation [37]. In Russia, forestry-related jobs clearly reflect forestry goals, rather than economic ones. In Finland, reforestation is covered from the forestry, technological, and economic perspective: commercial improvement cutting is based on rarely repeated, intense, and economically feasible cutting. The volume of commercial cutting in 2004–2007 was up to 40% of the total harvesting volume compared to 5% in the North-West of Russia. This is largely due to the fact that continuous logging in Russia is carried out at about half of the estimated cutting area, while in Finland – only at a quarter.

The adoption of intensive forest management in Finland in the 1960s increased the total timber supply by 53% and the average current growth –by 77%. This suggests that the country was able not only to preserve the natural capital of forests, but also to significantly increase it, even though it produces up to 8–9 times more timber than Russia per unit of felling area. During 1960–2010, Finland harvested more than 2.2 billion cubic meters of wood, which corresponds to its current forest supplies. In fact, this means that with modern reforestation techniques Finland was able to double the average felling rotation of 100–120 years.

Thus, the experience of developed countries with similar climates shows that the restoration model of forest management can also work in Russia. The authors' studies of this issue have shown that intensive forest management in the Komi Republic is possible only in the southern part, especially in the Priluzsky, Sysolsky, Koigorodsky, and Syktyvdinsky districts, as well as in some forest areas of the Kortkerossky and Ust-Kulomsky districts.

The timber complex in the Komi Republic reached the point where forest raw material supply does not significantly increase the volume of harvesting and processing of most valuable lumber log.

Therefore, it is necessary not only to take measures to restore forests, including through transition to intensive methods of reforestation, which is primarily the objective for forestry, but also to change the rules and approaches to timber harvesting. The analysis helps identify several modernization lines.

1. The transition from pioneer forest development to multiple use within the framework of a specific rental base. Mass use of selective cutting should become the

mechanism of such a transition: with only economically valuable wood withdrawn from the plot (up to 10–30% of total supply), the rest of it remains for "nursing" and is withdrawn after 5–15 years as it becomes "commercially valuable". This system is widely used in European, especially Scandinavian, countries and is suitable for Russia, given that lease agreements are concluded for up to 49 years.

2. Lifting restrictions on timber procurement in the Forest code under purchase/sale agreements for small businesses, as it is forbidden to construct forest roads, wood depots, , other buildings and structures in forest areas provided to small businesses for timber harvesting, which significantly complicates work. The results of assessing the segmentation of forest stands reveal a large number of high-quality forest areas where timber supplies are insignificant and are not of interest to medium and large business. Small businesses, however, cannot exploit them due to the existing restrictions. A mechanism to solve this problem may be increased duration of contracts by up to 2–3 years instead of the existing period of one year with the option to build permanent facilities.

3. Creating a plan for future development of forest resources (possibly is the framework of adjusting of the Forest plan of the Komi Republic), where small forest business would have reserved forest areas unattractive for major forest enterprises, taking into account their segmentation. In turn, major forest enterprises could receive compensation for transfer of these lands to small businesses, receiving other areas for cutting. Strengthening the influence of small forest business would increase the use of estimated cutting area, and therefore – increase resource efficiency.

4. Permission to limit commercial cutting in protected forests to preserve and improve the protective functions of these stands through selective logging.

Summary

The case study of the Komi Republic has revealed that the principle of continuous, sustainable use of forests declared in forestry is not observed.

It was found that some indicators of forest supply assessment proposed at the global level are not able to determine the specific features of intraregional changes. The method for calculating the estimated cutting area does not take into account the current forest depletion and all possible losses of timber, includes economically inaccessible forest resources, and most importantly, helps manipulate the cutting age, overestimating the cutting area, which leads to overexploitation and a significant reduction in the exploitation volume in the medium term. The value of estimated cutting area is an administrative value used for calculating rent and for other purposes but it has nothing to do with continuous and sustainable use.

A method to estimate forest resources and their depletion is developed based on comparing their real and reference state through changes in basic quality parameters – the share of lumber log, merchantability of forest stands, and fragmentation of forests. Comparison of reference parameters of forests with the actual values of parameters of raw material supplies identified when developing the General scheme of developing a network of forest roads in the Komi Republic to determine the actual depletion of forest resources. The authors present maps of large-scale differentiation of declining quality of forest resources for the development and selection of appropriate schemes of reproduction and use of forest resources.

The practical value of the research lies in the fact that it helps, on the one hand, adjust the strategy of socio-economic development of the Komi Republic in terms of locating promising logging and timber processing facilities taking

into account the availability of necessary forest resources; on the other hand, it helps develop new approaches to preserving natural capital of forests in a broad sense, especially in rural areas, where forestry plays an important role and is socially important for the local population. Moreover, the role of forest ecosystems to produce the full range of ecosystem services remains.

An important provision of the forest depletion assessment methodology is the consideration of segmentation in assessment of forest resources. It is implemented through analysis of spatial distribution of compartments of raw material supplies where average stem volume directly correlated with the quality of stands is above a certain threshold; in this case – above the national average stem volume for all raw material supplies. The density of adjacency of such compartments was also estimated; it directly affects the supply of raw materials for large or medium sawmills with raw materials at an acceptable cost.

The assessment revealed a significant depletion of forest capital throughout the region. The merchantability of timber since the beginning of industrial development of forests decreased in the southern regions to 50%, in the northern part, taking into account more unfavorable rehabilitation conditions – up to 75%. The depletion of high-value timber (lumber log, veneer block) in the past decade is growing faster, threatening the supply of raw materials for sawing and woodworking. Analysis of depletion of raw material supplies reveals a correlation between the actual decline in the volume of lumber log harvesting (5–6 times over the past 30 years) and the estimated depletion of forest capital (4–9 times for specific raw material supplies).

The assessment results confirm that the supply of large timber processing plants in the medium term is potentially unsustainable due to the inability to ensure stable supply of lumber log, which limits the growth of wood processing.

For restoration and preservation of forest resources of the Republic, as well as replication of the model for other forest subjects of Russia the combined application of three lines is proved:

1) forest management activities corresponding to reforestation potential;

2) recovery modernization of forest management, involving forest management in the form of periodically repeated cycle of selective felling followed by replenishment of supply at the expense of a younger generation of trees to form plantations of high economic value;

3) compensating strategy of wood processing using the best technologies for processing wood of decreasing quality.

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