The restoration of the Far Eastern forests in modern conditions and their effective use

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Abstract. The article summarizes the multi-year results of research of the Far Eastern forests restoration problem and their effective use in the present-day conditions. The forests of the Far Eastern Federal District of Russia are of great economic, social and ecological importance. At the end of the XX century intensive forest use with predominance of continuous concentrated felling in multi-forest areas of the region, wood fires, development of mineral deposits led to depletion of forests, reduction of their qualitative composition and productivity. In addition, natural regeneration of cutover stands does not always ensure their afforestation. It can occur slowly with the change of economically valuable conifers and hardwoods by soft-leaved, undesirable trees and bushes. Therefore, one of the main tasks in forest reproduction is timely and high-quality reforestation, including artificial forest regeneration using innovative technologies. In this regard, the aim of the research is to develop the scientific bases of reforestation in the Far Eastern forests under modern conditions to develop innovative proposals for improving their state.

1. Introduction

The Far Eastern forests are unique by a wide variety of forest formations (cedar-broad-leaved, spruce-fir, larch, pine trees, stone birch forests and others), by abundance of wood-shrub vegetation species, powerful potential of natural reforestation processes and emergency fire hazard and forest fire-danger. The value of forests consists not only in providing wood and non-wood forest products, but also as a "the lungs of the planet", as the most active carbon dioxide absorbents and carbon accumulation in forest ecosystems. This role of forests is particularly increasing due to global climate change – increasing of air temperature and CO₂ concentration in the Earth's atmosphere. At the same time, as noted by a large group of the Far Eastern scientists [1] "In the last decade, the natural resources use in the Far Eastern Federal District (FEFD) has become a way to environment breakdown, and to an environment crisis in the years of transition." At present, the main idea of environment management is to find a complex balance between the need of the current use of natural resources and preservation of their part for future generations, as well as between the use of resources and their restoration [1]. Reforestation still remains an acute and complex both economic and environmental problem. First of all, it is closely connected, with the continuous felling, the technology of cutting area operations, logging machines used, especially for tree length skidding. At the end of the XX century, the intensive forest use with predominance of clear felling in the multi-forest areas of the region, forest fires,
mineral deposits development led to forests depletion, reduction of their quality composition and productivity. Besides that, the natural regeneration of cutover stands does not always ensure their afforestation. It can occur slowly with the change of economically important conifers and hardwoods by soft-leaved, undesirable trees and bushes. Therefore, one of the main tasks of forests reproduction is timely and high-quality reforestation, including artificial, using innovative technologies. In this regard, the aim of the research is to develop the scientific bases of reforestation in the Far Eastern forests under present-day conditions to develop innovative proposals for improving their state. Based on the following tasks have been determined: 1. To analyze and summarize the existing experience of forest restoration in Russia and abroad; 2. To assess the present state of reforestation in the Far East forests; 3. To propose innovative solutions to the reforestation problem in the FEFD.

2. Materials and methods
The objects of research were the forests of Khabarovsky, Primorsky and Kamchatka Krais, as well as the Amur, Sakhalin, Magadan Regions, the Jewish Autonomous Region (EAO), the Republic of Sakha (Yakutia) and the Chukotka Autonomous Okrug (ChAO). The restoration of forests in these territorial entities was assessed using literary data and the results of research conducted by the FEFRI employees [2-9]. The studies were guided by the normative-legal documents (Forest Code of the Russian Federation [10] and the Rules of Reforestation [11]).

3. Results and discussion
The forests of Russia, including the FEFD, are the most significant natural resources of our country and the main suppliers of economic and valuable timber. Therefore, the protection of forest resources, their rational use and reproduction with the biological diversity preservation should be a priority in the environment protection. However, they are intensively involved in the logging process, which leads to the decrease of their percentage in the total share of planted forests, which threatens the biological diversity loss and increase in the proportion of forest areas covered by low-value hardwoods. In this regard, there is an urgent need to develop the measures and conditions for the successful natural regeneration of forests. For example, under the conditions of the FEFD or Siberia, the natural method of reforestation should be considered predominant [1-3, 8, 12-14]. Taking this into account, the questions concerning the studies of regularities of reforestation processes at felling areas and increase of their efficiency continue to be relevant, they were considered in a number of works (Vasilyev, Babintsev, Kovylin, Denisov, Rusova, etc.) [15-18]. At different time the forest reproduction problems were studied by famous scientists and practitioners (Turskiy, Morozov, Sukachev, Timofeev, Melekhov, Bolotov, Pobedinskiy, Alekseev, Babintseva, Obydennikov, Kovylin, Abaimov, Denisov, Runova, Savchenkova, Buzikin, Farber, Gabdrakhimov). The authors showed that forests, being self-restoring natural resource, need rational use and effective reproduction (Melekhov, Utkin, Lur). The researchers noted the importance of choosing the method of forest reproduction after felling, it should ensure the restoration of not only planting, but also the peculiar flora and fauna (Melekhov, Moiseyev, Belov, Kishenkov, Martynov, Farber) [19-26]. The researchers have found that the forestry efficiency of natural restoration depends on many factors and can be quite high, allowing in some forest areas to rely on natural reforestation, as the basic way of forest reproduction, for example, in the FEFD (Vasilyev, Pshenichnikova, Ivanov, Denisov, Runova, Savchenkova). However, it should be recognized that if the FEFD natural renewal of cutover stands does not always provide for their afforestation. It can be slow with the change of economically valuable conifers and hardwoods by soft-leaved, undesirable trees and bushes. Therefore, timely and high-quality reforestation is one of the main aims of the forest management using innovative technologies. In the course of the assessment of reforestation in the Far East forests, the authors were guided by normative-legal documents: The Forest Code of the Russian Federation [10] and the Rules of Reforestation [11]. The requirements of these documents include the reforestation of felled, dead or damaged forests, the preservation of biological diversity and the beneficial functions of the forest. It is known that three methods of reforestation are used: natural, artificial and combined. For natural reforestation regenerative forces of
nature (undergrowth or self-sowing) or various types of influence (aid) are used. Forest stands are created in artificial reforestation. Combined reforestation is used when the restoration exists, but in insufficient quantities, and in such cases it is supplemented by the forest stands. In the course of 2017 research on the topic of "Study of the geographical variability of the main forest-forming species of the Far East", the following ratio of the reforestation methods volume in % was established for the region's entities (Table 1) [4].

| Entity                        | Forest region       | Method of reforestation, % | Natural | Artificial | Total |
|-------------------------------|---------------------|----------------------------|---------|------------|-------|
| Jhabarovsky Krai              | FEFTR\(^a\)         |                            |         |            |       |
|                               | PPCBFR\(^b\)        |                            |         |            |       |
| Primorsky Krai                | FEFTR               |                            | 91      | 9          | 100   |
|                               | PPCBFR              |                            | 92      | 8          | 100   |
| Amur Oblast                   | FEFTR               |                            | 90      | 10         | 100   |
|                               | PPCBFR              |                            | 92      | 8          | 100   |
| Jewish Autonomous Oblast      | FEFTR               |                            | 60      | 40         | 100   |
| Sakhalin Oblast               | FEFTR               |                            | 85      | 15         | 100   |
|                               | PPCBFR              |                            | 50      | 50         | 100   |
| Kamchatka Krai                | FETFOTR\(^d\)       |                            | 100     | –          | 100   |
|                               | KTR\(^e\)           |                            | 85      | 15         | 100   |
| Magadan Oblast                | FETFOTR             |                            | 100     | –          | 100   |
|                               | FEFSR               |                            | 100     | –          | 100   |
| Republic of Sakha             | ESTFOTR\(^f\)       |                            | 100     | –          | 100   |
| (Yakutia)                     | ESTFOTR\(^g\)       |                            | 100     | –          | 100   |
| Chukotka Autonomous Okrug     | FETFOTR             |                            |         |            |       |

\(^1\) FEFTR – Far Eastern Taiga Forest Region  
\(^2\) PPCBFR – Priamurye-Primorye Coniferous–Broadleaf Forest Region  
\(^3\) FEFSR – Far Eastern Forest-Steppe Region  
\(^4\) FETFOTR – Far Eastern Tundra Forests and Open Taiga Region  
\(^5\) KTR – Kamchatka Taiga Region  
\(^6\) ESTFOTR – East Siberian Tundra Forests and Open Taiga Region  
\(^7\) ESTFOTR – East Siberian Tundra Forests and Open Taiga Region

The table is indicative of the natural reforestation predominance in all entities of the FEFD. In the absence of forest fires, the multi-species Far Eastern forest ecosystems have a high natural potential for reforestation and are successfully restored. It should be noted that during the studies of the topic "Assessment of the impact of forest activities on the carbon cycle..." in 2016-2017 [6] it was revealed, that during photosynthesis these forests more actively absorb carbon, thus causing the outflow from the atmosphere, in comparison with mono-species artificial stands. Professor E V Titov [27] notes that the forest is a unique work of nature, possessing the self-restoration capacity and improvement of wood-shrub species in the evolution process. Natural selection takes place during the life competition, the strongest specimens, adapted to these conditions, which become the new wood seed generation, are preserved. The undergrowth is a young generation of the main species, selected by life competition and natural selection, capable to form a new forest stand. It originates from the seeds of the best parent trees – the winners in the local population [27]. E V Titov believes that keeping the undergrowth...
preserving is a compulsory measure to promote natural renewal. This will allow to preserve the local population, the valuable genofond selected by nature, the soil integrity and fertility, prevent undesirable change of species, not using labour-intensive expensive and inefficient forest cultivation work, cut the cost of reforestation to a half and a third [27]. Wood harvesting has the strongest impact on the dynamics and state of the Far Eastern forests. According to A P Kovalev [2, 3], over the last 20 years the most valuable coniferous forests, especially spruce and fir-trees, have been replaced by leafy forests. Their degradation is connected with the felling system. In the forests of the Khabarovsky Krai, Amur Oblast and the Republic of Sakha (Yakutia), continuous felling was 80-95%. This practice of forest management leads to species changing and promotes occurrence and propagation of forest fires destroying a tree cover and a fertile soil layer. The burned forests turn to incomplete leafed or coniferous-leafed stands.

To improve the situation, it is necessary to reduce the localized clear felling and the transition to a system of partial cuttings, which will ensure the preservation of the forest environment, undergrowth, rapid rehabilitation of forest stands, and they will contribute to the continuous sustainable forests use. The greatest distribution should be obtained by: selective felling in stands with density of 0.7 and more; long-gradual felling in stands with the 100-600 pieces/ha of lighter trees of the main species; alternate strip gradual felling in wind-resistant coniferous stands. Different types of partial cuttings should be applied in view of the forest formation, state and the characteristics of the stand. There is no universal felling method that optimally meets forest exploitation and forestry demands. In each concrete case it is necessary to take into account: zonal-typological and vegetative conditions; forest group of target and ecological purposes; species composition, age structure, forest stand structure and dynamics; presence and status of advance regeneration; a degree of slope and its exposition; the subsoil and soil bearing capacity.

In the recent years, the logging situation in the FEFD is beginning to change gradually. So, as of 01.01.2018 (12-OIP) selective cuttings in ripe and over-stable stands were 55%, they were mainly voluntarily-selective. In the forest fund of the FEFD millions of hectares of incomplete and disturbed stands are concentrated. To rehabilitate them the FEFRI researchers developed the recommendations of logging in them, including felling methods and technologies, promotion of natural reforestation, fire protection, felling care, partial forestry crops [14]. As noted above, the Far Eastern forests are characterized, in the absence of forest fires, by a successful natural reforestation, which can be regulated by forest care felling. At present, these cuttings are very limited in use. In 2017, their area in the FEFD amounted only to 40.7 thous. hectares, including thinning – 74.0%, removal and cleaning – 20.9%. New methods of felling care, introduced by the Rules of Forest Care, approved by the Order of the Ministry of Natural Resources of the RF, November 22, 2017, No 626 [28], and aimed at improving the forests productivity, improving the species and quality composition, creating the conditions for natural reforestation, almost have not been carried out. So, in 2017, regeneration felling was carried out at the area of 495.7 hectares, restocking felling –21.4 hectares, conversion cuts of uneven age stands – 642 hectares. Forest sanitations improving the state of forests are also carried out at small areas: in the coniferous forestry–8.4 thous., in hardwood– 0.51 thous., in soft-wood – 0.65 thous. hectares. These insignificant volumes were executed at the area of a forest fund – 500 million hectares (45% of forests of the Russian Federation), the total area of operational forests being – 107 752 thous. hectares.

The Far Eastern authors [28-32] estimating artificial reforestation in the FEFD, noted that despite the considerable costs, the forest crops have no significant impact on the forest fund state. Forest cultivation activities in the FEFD should be supported at the experimental level, creating a backlog of knowledge and experience for a more distant period. At the same time the valuable local tree species should be used: cedar, larch, pine, spruce, fir, ash, oak with obligatory observance of forest-seed zoning. It is possible to introduce fast-growing valuable introduced species, according to the previous experiments well proven in certain conditions. A combined method of reforestation was not applied at all in the FEFD. When analyzing reforestation works in the period of 2007-2016, it was established that the method of combined reforestation was used in 2016 at the area of 40 hectares in the Primorsky
Krai. At the same time, this method of reforestation can be applied in significant areas and give positive results with less financial and labor costs, considering the current state of the FEFD Forest Fund.

Forest plantations in the FEFD are not currently being created. But the prospect and expediency of their creation can be justified: presence of territories with favorable forest conditions, low rates of payment for a unit of a forest plantation area and their exploitation [33] (this rate in the FEFD entities is 3.39 rubles per hectare per year (for comparison, in Karelia – 32.97 rubles, and in Voronezh and other entities of the RF – 62.48 rubles) [30]; by quite a large number of fast-growing local wood species: larch, pine, poplar, ash, etc. [5]. In the Kamchatka Krai and the Sakhalin obstal it is expedient to create forest-resource plantations of the Siberian larch introduction. Under specified conditions 45-50-year plants of this species are growing by I, I A, I B classes of forest appraisal index, and at this age have a reserve up to 200-250 m3/ha, characterized by high biological stability. Now, the creation of Siberian larch crops is prohibited by legislation, as non-zoned seeds using. Prof. I. V. Shutov [29] believes that if the creation of forest-resource plantations in Russia starts, it will save our boreal forests and will effect the preservation of huge carbon stock deposited from the atmosphere. In the Khabarovsk Krai there is a successful experience of creation in 1988-1989 of a forest seed grafting plantation of the Korean cedar (Pinus koraiensis Sieb. et Zucc.) in Khektshir Experimental Forestry enterprise of FEFRI. The area of the plantation is 4 hectares, where the vegetative offspring of the Oborsky and Khorsky populations of the Korean cedar are planted.

The FEFRI employees conduct periodic surveys of the preservation, condition and yields of the object. High yield of seeds was marked. The seeds are being collected, the planting material is growing from them. The plantation is a valuable object for further research. High-yielding clones are identified as the valuable breeding material. The development of plantation forestry in the FEFD can become an innovation in forest management and will allow to preserve valuable natural low-disturbed forest areas (LDFA), which, according to WWF [9] are concentrated in 13 countries, including the boreal forests of the Russian Federation. The LDFA ensures the conservation of biodiversity and is a carbon runoff, ensuring its absorption and accounts for about 20% of annual emissions from anthropogenic sources [9]. In the process of solving the reforestation problem, it is necessary to take into account the emergency fire hazard and the fire frequency of forest plantations, including a whole range of measures (monitoring, fire-fighting arrangement of the territory, propaganda and agitation, etc.). It is necessary to pay special attention to the forest fires prevention, which also consists in protective fire-resistant strips of fire-resistant wood species – poplar and larch. It is expedient to consider them not only as the measures of fire territory arrangement, but also as the actions of artificial reforestation and the basic direction of phytomelioration in the Far East Federal District.

The objects of reforestation can be the areas disturbed by mining, which have been mainly withdrawn from the lands of the forest fund (more than 800 thousand hectares). They include dumps, tailings, settling tanks, etc., the most difficult of which are the tailings, where the toxic mineral processing waste with negative impact on the ecological sphere, is stored. Therefore, in the FEFD there was a need to develop a technology for forest reclamation of the natural environment to return the withdrawn land to the forest fund. Their self-overgrowth is practically impossible due to unfavorable agrophysical and chemical properties (high toxicity of tailings material). The available experience of this problem research testifies that in Russia, there are practically no publications containing constructive critical assessments of reclamation practice and practical application of alternative reclamation methods and technologies of the similar objects. The possibility of accelerated creation of efficiently functioning soil and ground horizons at the waste areas as the most important structural unit of the restored biogecosis has not been studied. Our research has proved the possibility of reclamation of tailings surface containing toxic mineral processing waste, using the potential of biological systems (bioremediation), the novelty of which is confirmed by the Patents of the Russian Federation No 569582, 2486733, 2625469, 2628581 etc [34-36]. Under production conditions the introduction of the proposed innovative methods of reclamation of the areas contaminated with toxic heavy metal and arsenic compounds was successfully carried out.
4. Conclusion
To improve the state, dynamics, productivity and ecological value of the Far Eastern forest ecosystems under present conditions it is necessary to:

- Develop and use perspective innovative system of forests fire protection, giving the main attention to fire prevention, including the whole set of measures (monitoring, fire-fighting arrangement, propaganda and agitation, etc.).
- For wood production, use the means of felling, considering the state of the forest area and contributing to the preservation of the forest environment and possibility of further natural reforestation or providing measures for cutting, both for continuous and selective methods of felling;
- natural reforestation should be considered the main method of reforestation taking into account the power of nature's regenerative forces in the Far Eastern forests, as well as the low economic and forestry efficiency of artificial reforestation.
- Apply widely the various measures to promote natural reforestation and to intensify focused forest care (regeneration felling, reforming or reconstruction of forest plantations). Such care felling at considerable areas in the FEFD of the disturbed and thin stands, will give economic, ecological and social effect.
- In the forest areas of the Far East with favorable forest growth conditions and low payments for 1 hectare of forest site, the establishment of wood plantations can become an innovation in forest management [33] and will allow to preserve the valuable natural low-disturbed forest areas (LDFA). The LDFA are a wildlife that preserves biodiversity, are a source of carbon and are opposed to global climate change [9].
- Reduce the negative impact of deforested areas being a result of mineral deposits development, it is necessary to carry out forest reclamation (technical and biological stages) according to the proposed innovative technologies using the potential of biological systems (bioremediation).

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