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PRODUCTIVITY OF PINE PLANTATIONS DURING RECLAMATION OF SAND QUARRIES

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Abstract. Restoration of lands disturbed by anthropogenic impact is currently the most urgent issue in the light of the gradually decreasing area of commercially valuable plantations. Reclamation of quarries includes restoration of artificial landscape by carrying out various kinds of measures. We have surveyed the quarries located in the northern districts of the Arkhangelsk region. These quarries were used for sand mining in the construction of roads of federal and regional importance. No forestry activities were carried out in one of the quarries. It was adopted as a control site and abandoned to natural regrowth. Deciduous trees and shrubs (birch, willow) in some places grow there after a decade and a half. In two other surveyed quarries mechanical soil treatment was carried out and seedlings of Scots pine (*Pinus sylvestris* L.) were planted. This species is used for planting on sandy soils to form valuable productive stands. Studies have shown that pine young stands of the second age class have quality class II, with the average forest inventory values of a diameter of 14.6 cm, a height of 15.6 m and a stock of 168 m^3/ha. The plants are healthy, physiologically developed with the average annual increment of 56 cm over the last decade. Forestry measures effectively carried out in the development of sand quarries, firstly, provide the necessary optimal conditions for growth and development of plants, and, secondly, biologically productive areas of the land surface are formed due to forest reclamation. These territories are an excellent reserve for increasing the areas covered by forest vegetation.
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Keywords: sand quarry, forest plantations, pine, disturbed lands, land reclamation, reforestation.

ПРОДУКТИВНОСТЬ СОСНОВЫХ НАСАЖДЕНИЙ ПРИ РЕКУЛЬТИВАЦИИ ПЕСЧАНЫХ КАРЬЕРОВ

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Оригинальная статья / *Поступила в редакцию 03.05.20 / Принята к печати 13.08.20*

Аннотация. Восстановление нарушенных антропогенным воздействием земель в связи с постепенным уменьшением площади хозяйственно-ценных насаждений является в настоящее время актуальным вопросом. Рекультивация карьеров включает в себя восстановление искусственного ландшафта путем проведения различного рода мероприятий. Цель исследования – определение эффективности проведенных лесохозяйственных мероприятий искусственного лесовосстановления в песчаных карьерах Архангельской области. Обследованы карьеры в северных районах региона, использовавшиеся для добычи песка при строительстве дорог федерального и регионального значения. В одном из карьеров, выбранном в качестве контроля, лесохозяйственные мероприятия не проводились, и он был оставлен под естественное заращивание. Спустя полтора десятилетия карьер частично зарос лиственными деревьями и кустарниками (береза, ива). В двух других обследованных карьерах осуществлена механическая обработка почвы и высажены сеянцы сосны обыкновенной (*Pinus sylvestris* L.). Именно эту породу применяют для посадки на песчаных землях с целью формирования ценных продуктивных древостоев. Показано, что сосновые молодняки второго класса возраста имеют класс бонитета II, средние диаметр, высоту и запас – 14,6 см; 15,6 м и 168 м^3/га соответственно. Растения здоровые, физиологически развитые, их средний годовой прирост за последнее десятилетие составил 56 см. Эффективно выполненные лесохозяйственные мероприятия при освоении песчаных карьеров, во-первых, обеспечивают необходимые оптимальные условия для роста и развития деревьев, а во-вторых, способствуют формированию биологически продуктивных участков почвы. Рекультивированные карьеры являются отличным источником преумножения площадей, покрытых лесной растительностью.

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Ключевые слова: песчаные карьеры, лесные культуры, сосна, нарушенные земли, рекультивация земель, лесовосстановление.

Introduction

Reclamation of disturbed lands involves restoration of landscape, soil structure and fertility, hydrological regime of the area, along with reproduction of successions through a set of engineering (technical), agrotechnical, silvicultural and biological measures. These works are regulated by the Decree of the Government of the Russian Federation No. 1724-r dated September 26, 2013 “On Approval of the Basis of the State Policy in the Use, Preservation, Protection and Regeneration of Forests in the Russian Federation for the Period up to 2030” and by the Forest and Land Codes of the Russian Federation. The primary regulatory document for reclamation of disturbed lands in the forestry sector is “The Rules of Afforestation”, which were developed on the basis of the Article No. 63 of the Forest Code and approved by the Order of the Ministry of Natural Resources of the Russian Federation No. 149 on June 8, 2007.

Forestry-based reclamation includes the creation of various types of forest plantations on disturbed lands. Forest reclamation should be carried out on anthropogenically disturbed areas of all categories, as well as on adjacent territories that have completely or partially lost their productivity. The complex of unfavorable

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factors, the major of which are unfavorable water regime and poverty of soil in elements of mineral nutrition, is the hinder of the natural reclamation of these areas [8]. A number of authors [4, 6, 11, 13, 17, 19, 21, 22, 24] point that together with planting of woody vegetation in those areas where the ground cover grows poorly and on infertile soils, it is essential to create simulated sword of perennial grasses. For instance, Kazakov L.A., Vishnyakov G.V. and Chamin V.A. [9] recommend sowing sand ryegrass on the Kola Peninsula.

Likhanova I.A. and Kovaleva V.A. [12] emphasize that by selecting optimal measures for a particular reclamation object it is possible to accelerate the formation of forest plantation (soil and microbial composition, living ground cover and tree layer) due to managing the competitive relationship between the components of anthropogenic phytocenosis.

During the construction of forest roads, as well as roads of regional and federal importance in the Arkhangelsk region, sand mined in quarries is used. Such quarries are ubiquitous in the territory of the Northwestern Federal District.

The research purpose is to determine the effectiveness of the forestry measures carried out through artificial reforestation in sand quarries of the Arkhangelsk region.

Research objects and methods

In the course of the scientific inquiry, various sites of the land surface were sampled after sand mining. These quarries were developed in the construction of roads of regional and federal importance. They are located in the northern districts of the Arkhangelsk region.

Sand quarry No. 1 with an area of 6 ha is located in the north of the region in the Kholmogory forestry close to the technological route of the nearby timber industry enterprise. This site was used for sand harvesting with the purpose of construction of this forest road. Forest reclamation work was carried out in 1987. The surface was levelled by a bulldozer blade before tillage in the quarry. Forest cultivation technology includes: plowing of loosened microhills by an auger plow PSh-1 together with a tractor LKhT-100; manual planting of 2-year-old standard seedlings of Scots pine (*Pinus sylvestris* L.) in microhills using Kolesov's sword according to the scheme 0.6×3 m (fig. 1, *a*). This cultivated species was not randomly chosen, since it is used for planting on sandy soils to form valuable and productive stands. The initial density of forest plantations is 5,550 pcs/ha. Single specimens of willow appeared in the quarry before the forestry measures.

Sand quarry No. 2 with an area of 1.5 ha was developed in 2003 for the construction of the Arkhangelsk-Karpogory regional road. Forest reclamation work was carried out two years after sand mining. The surface was graded by the bulldozer blade prior to tillage in the quarry. The technology of forest cultivation works was as follows: preparation of fire lines 1.2 m wide with a wedge-shaped pusher TK-1,2 together with a tractor LKhT-55M; manual planting of 2-year-old standard seedlings of Scots pine (*Pinus sylvestris* L.) in the middle of the line using Kolesov's sword according to scheme 0.5×3.5 (fig. 1, *b*). The seedlings were grown in the greenhouse of the Kholmogory forestry. The initial density of set out plants is 5,800 pcs/ha.

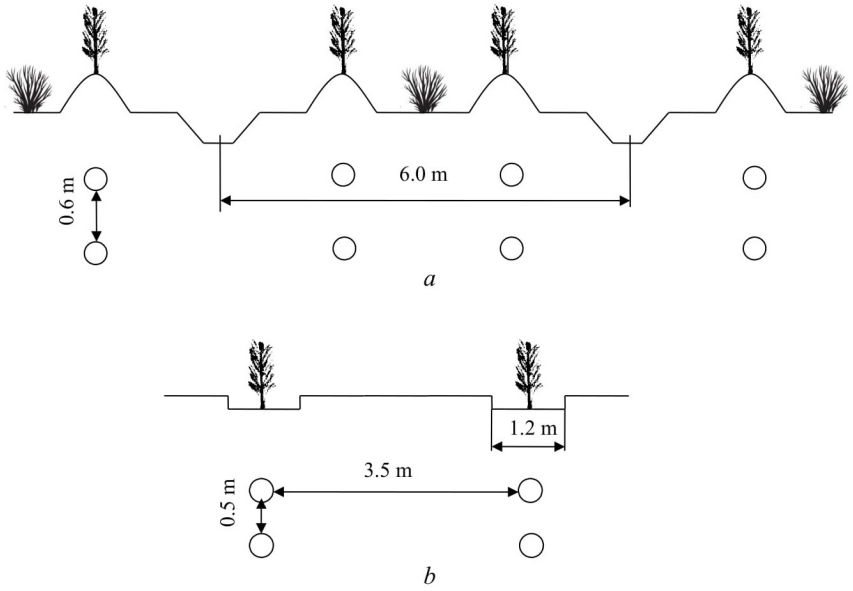

Fig. 1. Technological scheme of forest plantations: *a* – sand quarry No. 1; *b* – sand quarry No. 2

Sand quarry No. 3 with an area of 5 ha developed in 2003 in the vicinity of the Lukovetsky settlement was chosen as a control site. This area was left under natural regrowth and after sand mining no forest management activities were carried out here. There are 1,525 pcs/ha of seed birches and 1,348 pcs/ha of willow bushes after 17 years.

The survey of stands in the quarries was carried out according to generally accepted methods and techniques [10, 14, 15, 18, 20]. The height, diameter, and annual increment of pine trees were measured for the last 10 years; and the number of surviving plants was determined.

The ground cover in the forming plantation phytocenoses was studied on the test plots of 1×1 m size, which were laid out evenly over the area according to the method of Astrologova L.E. and Gortinskiy G.B. [3].

Undergrowth was counted by size, vital condition, and species composition on the test plots of 2×5 m size, based on the method of Melekhov I.S. [16]. Simultaneously, understory species were recorded and classified according to their species composition and vital condition. The number of recorded plants was converted per hectare.

Research results and discussion

In order to restore economically valuable lands and minimize environmental damage, it is necessary to reclaim disturbed anthropogenic territories. There is an initial period (i.e. the time interval during which, in the territory devoid of any vegetation, the first representatives of flora appear) on technogenic lands – rock dumps, abandoned quarries, right-of-ways along roads under construction, gas and oil pipelines, friable sands and alluvial deposits [4, 8].

Regulatory requirements for forest reclamation are reduced to creation of biologically productive areas of land surface with the necessary conditions for plant

growth and development without fertile soil coating. The floristic composition of these areas is formed gradually, starting with the ground cover and ending with the stand.

The productivity of plants in the living ground cover depends on the nature of vegetation and, consequently, on the age of plantations. Meadow grasses with the greatest distribution in sand quarry No. 1 form a larger phytomass per area unit. In sand quarry No. 2, where the abundance of meadow species is much lower, the value of this parameter decreases. During growth of forest plantations, the dominant ecological groups of plants in the living ground cover change from meadow and meadow-grassland to typically forest species.

The living ground cover is very diverse in pine plantation phytocenoses of the second age class. The upper layer consists of rosebay willowherb (*Chamerion angustifolium* (L.) Scop.), wild angelica (*Angelica sylvestris* L.), woodland geranium (*Geranium sylvaticum* L.), tufted vetch (*Vicia cracca* L.) and Paris herb (*Paris* L.). Next are berry prostrate shrubs: bilberry (*Vaccinium myrtillus* L.), stone bramble (*Rubus saxatilis* L.), and cowberry (*Vaccinium vitis-idaea* L.). Except that, Arctic starflower (*Trientalis europaea* L.), tufted sedge (*Carex gracilis* Curt.) and wood sorrel (*Oxalis acetosella* L.) can also be found.

In the living ground cover of pine plantation phytocenoses, those representatives of flora grow first, root system of which at the beginning of the vegetation period (i.e., even before the establishment of constant summer temperatures) develops in the lower soil horizons with lower temperatures and higher humidity. Plants with large annual height increment, intensive seed reproduction, actively creating vast biogroups, shading the soil surface and protecting root systems from overheating dominate here. An outstanding example is wild strawberry (*Fragaria vesca* L.), as well as a long-rooted species, such as rosebay willowherb (*Chamerion angustifolium* (L.) Scop.), the buds of which lie at a considerable depth, where temperatures are lower [1, 2].

Soil overgrowth depends on the soil horizons that form the tillage layer. In soil preparation, when microhills are formed only from the humus-accumulative horizon, which is clogged with seeds of herbaceous vegetation without involving the underlying mineral soil horizons in tillage, the intensity of their overgrowth increases [2].

Sand quarry No. 2, in connection with the depletion of elements of mineral nutrition in soil horizons, is characterized by relatively low species representation of the living ground cover. Overgrowth of the cultivated soil with herbaceous vegetation is weak here. The dominant species in the quarry are the following: wood horsetail (*Equisetum sylvaticum* L.), rosebay willowherb (*Chamerion angustifolium* (L.) Scop.), and coltsfoot (*Tussilago farfara* L.). There are also chamomile (*Matricaria chamomilla* L.), red clover (*Trifolium pratense* L.), and tufted sedge (*Carex gracilis* Curt.).

When taking into account natural regeneration of woody species, we found that in the intergrowth space of sand quarry No. 1 unaffected by tillage 5,880 pcs/ha of seed birch (*Betula pendula* Ehrh.) grow and on the whole area there are 4,100 pcs/ha of viable spruce (*Picea abies* Link.) undergrowth: small – 2,114 pcs/ha, medium – 1,179 pcs/ha, and large – 807 pcs/ha. In the lower storey there are isolated specimens of juniper (*Juniperus communis* L.) and mezereum (*Daphne mezereum* L.), there are 1,520 pcs/ha of bay willow (*Salix pentandra* L.), which appeared here mainly before the forestry works.

Sand quarry No. 2 is surrounded on three sides by the forest stand of natural origin, so that 15,200 pcs/ha of birch (*Betula pendula* Ehrh.) are located evenly over

the studied area. Under the canopy of pine and deciduous young stands 2,800 pcs/ha of viable young spruce (*Picea abies* Link.) grow, mostly small and medium. When studying the lower storey, 5,800 pcs/ha of bay willow (*Salix pentandra* L.) appeared here mainly before the beginning of forest reclamation were recorded.

During reconnaissance survey of quarries the most typical sites of formed plantation phytocenoses were found for each object. On the sites the survey of artificially created pine young growth was carried out, forest inventory characteristics of which are given in table.

Growth course of pine plantation phytocenoses in the sand quarries

Plantation age, yrs	Average			Survival rate, %	Density	Stock, m^3/ha	Quality class
	Height, m	Diameter, cm	Increment, cm				
Sand quarry No. 1							
27	11.8±0.81	11.5±0.30	61±0.44	57.4±0.89	0.9	152	II
34	15.6±0.99	14.6±0.57	62±0.49	57.0±1.02	0.9	168	II
Sand quarry No. 2							
9	3.0±0.02	2.8±0.03	42±0.22	77.7±0.69	0.7	18	II
16	6.1±0.37	5.9±0.05	46±0.26	75.0±0.70	0.8	44	II

The research results show that highly productive stands with positive dynamics of productivity increase are formed on the surveyed sites of land surface. Thus, the stands of the second age class (sand quarry No. 1) reach a height of 15.6 m with an average diameter of 14.6 cm. The current annual increment of these stands is on average 62 cm. The value of increment is influenced by the uniform distribution of trees over the area with the survival rate of 57 % and density of 0.9 m^2/ha. The composition of the plantings is 9P1B (9 pines, 1 birch). Forest plantations accumulate a stock of 168 m^3/ha and have quality class II, which exceeds the average quality class in the Arkhangelsk region. Average value of quality class for coniferous plantations in the region is IV.7 (4.7).

At the same time, there is a series of works in this field in different parts of our country, where researchers represent the data, which are somewhat different. Thus, Nureeva T.V. et al. [17], surveying pine plantations created with different planting spacing in quarries, point that the height of 12-year-old plantations varies from 4.2 to 4.6 m depending on the density of creation, and the diameter varies from 3.8 to 5.9 cm. Zalesov S.V. et al. [23] provide the data obtained in the Sverdlovsk region. Pine forest plantations at the age of 9 have quality class II with a height of 2.6 m, a diameter of 3.7 cm, forming a stock of 5.63 m^3/ha. Gavrilova O.I. [7] carried out a similar study of pine plantations in gravel and sand quarries of the Republic of Karelia and came to the conclusion that in some quarries the height of 9-year-old trees is 2.25 m, and in other areas 12-year-old trees reach 1.0–1.2 m in height.

In sand quarry No. 2 pine trees of the first age class grow according to quality class II accumulating a stem stock of 44 m^3/ha. The average height of pine trees is 6.1 m with a diameter of 5.9 cm. Herewith, at this site there are 75 % of preserved physiologically healthy proportionally developed trees. The composition of the plantings is 8P2B (8 pines, 2 birches).

According to the forest inventory parameters of plantations, we can judge that the technology of creation of artificial young growth on the recultivated lands is fulfilled according to the available requirements, which is indicated by the average

height increment of plantations (fig. 2). The values of increment mainly vary depending on the weather conditions of a particular vegetation period. In warm, moderately humid summers, the increment of pine trees is the maximal: in sand quarry No. 1 – 62 cm; in sand quarry No. 2 – 48 cm. The average annual increment for 10 years in sand quarry No. 2 is 43.8±0.07 cm, in sand quarry No. 1 – 55.8±0.14 cm. Deviation from the average value varies within 3–4 cm and 5–7 cm, respectively.

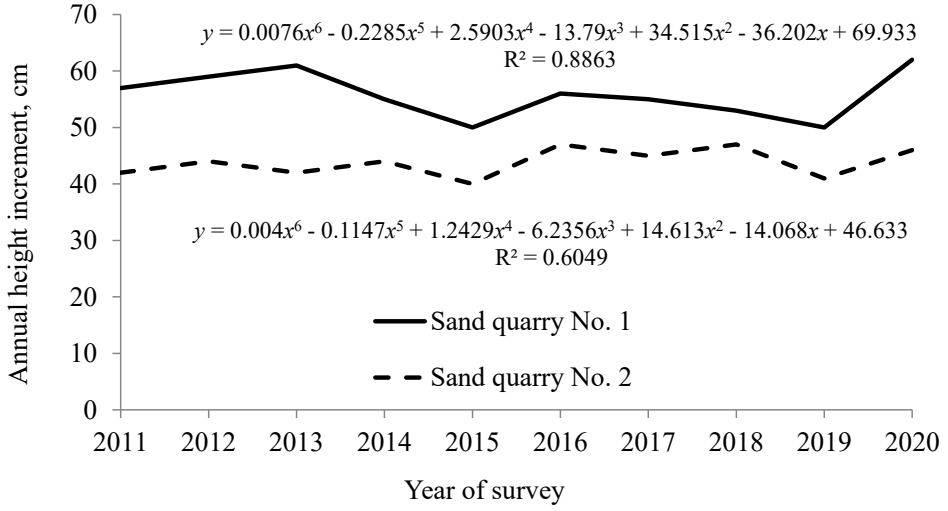

Fig. 2. Dynamics of annual height increment of pine plants in the surveyed areas (in the equation: y – increment, cm; x – age of pine plantations, yrs)

The growth curve is best approximated by polynomial function of the sixth degree. The coefficient of determination (R^2) in plantations of the second age class is higher than in young growth of the first age class and is 0.89 and 0.60, respectively.

Comparing the main forest inventory parameters of the surveyed young growth with the tables of growth rate of young pine stands of artificial origin, it is possible to conclude that forest plantations created in the reclaimed quarries are characterized by sufficiently high productivity. Thus, at the age of 34 in the Northern taiga forest inventory area the stock of forest plantations reaches 168 m^3/ha at the average height of 15.6 m. Quality class of pine plantations is II. Whereas, according to the growth rate tables given in the Forest Inventory Handbook for the North-East of the European Part of the Russian Federation [5], 30-year-old young pine forests of artificial origin in the Southern taiga forest inventory area have an average height of 10.9 m, average diameter of 8.2 cm and stock of 176 m^3/ha; and at the age of 10, the average height is 2.2 m, diameter is 2.6 cm and stock is 8.8 m^3/ha.

In addition to Scots pine, fast-growing deciduous species such as silver birch (*Betula pendula* Ehrh.) can also be recommended as a cultivated species on sandy areas based on the research and analysis of literature sources. Relying on the studies carried out in the Dendrological Garden named after V.N. Nilov of the Northern (Arctic) Federal University, American maple (*Acer negundo* L.) can also be recommended in these conditions.

Conclusion

The research results have shown that when forest reclamation work is ignored in the quarries after sand extraction in 17 years at such a site (control sample area No. 3) there are 1,525 pcs/ha of birch of seed origin, which is extremely insufficient for the formation of highly productive plantations.

At the same time effectively implemented forestry measures in the development of sand quarries No. 1 and No. 2, first of all, will provide the necessary optimal conditions for growth and development of plants, and secondly, will serve to form biologically productive areas of land surface. Pine young growth of the second age class is growing according to quality class II, have a stock of 168 m^3/ha with the average forest inventory values of diameter 14.6 cm and height 15.6 m. The plants are healthy, physiologically developed with an average annual increment of 56 cm over the last decade. These sites are an excellent reserve for increasing the area covered with forest vegetation.

REFERENCES

1. Astrologova L.E. *Types of Clearcuts and Reforestation of Tree Species*. Arkhangelsk, AGTU Publ., 2002. 96 p.

2. Astrologova L.E., Babich N.A. The Influence of Forestry Measures on the Composition of the Living Ground Cover in Pine Plantations. *Ecological Problems of the North. Interuniversity Collection of Academic Papers*. Arkhangelsk, SOLTI Publ., 1998, pp. 5–8.

3. Astrologova L.E., Gortinskiy G.B. *Methodology Guidelines for Field Practice in Botany*. Arkhangelsk, RIO ALTI Publ., 1980. 32 p.

4. Evans D.M., Zipper C.E., Burger J.A., Strahm B.D., Villamagna A.M. Reforestation Practice for Enhancement of Ecosystem Services on a Compacted Surface Mine: Path toward Ecosystem Recovery. *Ecological Engineering*, 2013, vol. 51, pp. 16–23. DOI: https://doi.org/10.1016/j.ecoleng.2012.12.065

5. *Forest Inventory Handbook for the North-East of the European Part of the Russian Federation: (Standards, Specifications and Guidelines for the Nenets Autonomous Okrug, the Arkhangelsk and Vologda Regions and the Komi Republic)*. Content by G.S. Voynov, N.P. Chuprov, S.V. Yaroslavtsev, S.V. Torkhov, A.P. Shusharin. Arkhangelsk, NRIF Publ., 2012. 672 p.

6. Franklin J.A., Zipper C.E., Burger J.A., Skousen J.G., Jacobs D.F. Influence of Herbaceous Ground Cover on Forest Establishment on Eastern US Coal Surface Mines. *New Forests*, 2012, vol. 43, iss. 5-6, pp. 905–924. DOI: https://doi.org/10.1007/s11056-012-9342-8

7. Gavrilova O.I. Restoration of Vegetation Cover in Sand and Gravel Quarries by Artificial Reforestation Methods. *Resources and Technology*, 2010, vol. 8, pp. 21–25. DOI: https://doi.org/10.15393/j2.art.2010.1739

8. Kapel'kina L.P. Analysis of the Experience of Forest Reclamation of Disturbed Lands. *Reforestation in the Volga Region: State and Ways of Improvement*. Yoshkar-Ola, VSUT Publ., 2013, pp. 62–68.

9. Kazakov L.A., Vishnyakov G.V., Chamin V.A. Forest Melioration of Kuzomen Sands. *Vestnik Kol'skogo nauchnogo tsentra RAN* [Herald of the Kola Science Centre of RAS], 2011, no. 2(5), pp. 58–63.

10. Kobranov N.P. *Survey and Study of Forest Plantations*. Leningrad, RIO LTA Publ., 1973. 77 p.

11. Likhanova I.A., Archegova I.B., Khabibullina F.M. *Restoration of Forest Ecosystems in Technologically Disturbed Territories of the North*. Yekaterinburg, UB RAS Publ., 2006. 104 p.

12. Likhanova I.A., Kovaleva V.A. Controlled Restoration of Forest Ecosystems on Sandy Technogenic Substrates in the Far Northern Taiga of the Russian European Northeast. *Vestnik Tomskogo Gosudarstvennogo Universiteta. Biologiya* [Tomsk State University Journal of Biology], 2018, no. 43, pp. 174–195. DOI: https://doi.org/10.17223/19988591/43/9

13. Macdonald S.E., Landhäusser S.M., Skousen J., Franklin J., Frouz J., Hall S., Jacobs D.F., Quideau S. Forest Restoration Following Surface Mining Disturbance: Challenges and Solutions. *New Forests*, 2015, vol. 46, iss. 5, pp. 703–732. DOI: https://doi.org/10.1007/s11056-015-9506-4

14. Maslakov E.L., Moyko M.F., Markova I.A., Kovalev M.S. *The Study of the Growth of Forest Plantations*. Leningrad, LenNIILKh Publ., 1978. 71 p.

15. Melekhov I.S. Issues of Diagnosis and Classification of Concentrated Clearcuts. *Concentrated Cuttings in the Forests of the North*. Moscow, AN SSSR Publ., 1954, pp. 48–60.

16. Melekhov I.S. *Forestry*. Moscow, Agropromizdat Publ., 1989. 302 p.

17. Nureeva T.V., Kuklina N.A., Chefranova M.N., Mukhortov D.I. Patterns of Growth and Formation of Scots Pine Species for the Purpose of Quarry Recultivation. *Vestnik Povolzhskogo gosudarstvennogo tekhnologicheskogo universiteta. Ser.: Les. Ekologiya. Prirodopol'zovaniye* [Vestnik of Volga State University of Technology. Ser.: Forest. Ecology. Nature Management], 2016, no. 1(29), pp. 57–68.

18. Ogiyevskiy V.V., Khirov A.A. *Survey and Study of Forest Plantations*. Leningrad, LTA Publ., 1967. 50 p.

19. Ortiz O., Ojeda G., Espelta J.M., Alcañiz J.M. Improving Substrate Fertility to Enhance Growth and Reproductive Ability of a *Pinus halepensis* Mill. Afforestation in a Restored Limestone Quarry. *New Forests*, 2012, vol. 43, iss. 3, pp. 365–381. DOI: https://doi.org/10.1007/s11056-011-9286-4

20. Rodin A.R., Merzlenko M.D. *Instructional Guidelines for the Study of Old-Growth Forest Plantations*. Moscow, VASKhNIL Publ., 1983. 37 p.

21. Skousen J., Ziemkiewicz P., Venable C. Tree Recruitment and Growth on 20-Year-Old, Unreclaimed Surface Mined Lands in West Virginia. *International Journal of Mining, Reclamation and Environment*, 2006, vol. 20, pp. 142–154. DOI: https://doi.org/10.1080/17480930600589833

22. Torbert J.L., Burger J.A., Schoenholtz S.H., Kreh R.E. Growth of Three Pine Species after Eleven Years on Reclaimed Minesoils in Virginia. *Northern Journal of Applied Forestry*, 2000, vol. 17, iss. 3, pp. 95–99. DOI: https://doi.org/10.1093/njaf/17.3.95

23. Zalesov S.V., Zalesova E.S., Zverev A.A., Opletayev A.S., Terin A.A. Artificial Reforestation on Reclaimed Lands in the Area of Pine-Birch Forest-Steppe Forests. *Problems of Forest Reproduction in the European Taiga*. Kostroma, KSU Publ., 2012, pp. 63–66.

24. Zipper C.E., Burger J.A., Skousen J.G., Angel P.N., Barton C.D., Davis V., Franklin J.A. Restoring Forests and Associated Ecosystem Services on Appalachian Coal Surface Mines. *Environmental Management*, 2011, vol. 47, iss. 5, pp. 751–765. DOI: https://doi.org/10.1007/s00267-011-9670-z

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