Natural regeneration features of broad-leaved species under the canopy of coniferous stands in forest-steppe conditions

V Tsaralunga¹, A Tsaralunga¹, N Yakovenko²* and A Zenishchev¹

¹Department of Ecology, Forest Protection and Forest Hunting, Faculty of Forestry, Voronezh State University of Forestry and Technologies named after G F Morozov, 8 Timiryazev Street, 394087, Voronezh, Russian Federation
²Division's Directorate of the Research Institute of Innovative Technologies and the Forestry Complex, Voronezh State University of Forestry and Technologies named after G F Morozov, 8 Timiryazev Street, 394087, Voronezh, Russian Federation

*E-mail: yakovenkonv@vgltu.ru

Abstract. The age structure of the undergrowth was studied using the technique of constructing the age spectra of the adolescent population, which revealed the regularities of the natural pine recovery process. The aim of the study was to conduct a comparative analysis of the broad-leaved species renewal under the coniferous (pine) plantations canopy in forest-steppe conditions using the example of the Belgorod region. The research was carried out on 21 test areas using standard silvicultural techniques to assess natural regeneration effectiveness. Quercus robur L. and Ulmus laevis Pall. prevail among deciduous species in the second layer. Tilia cordata Mill., Fraxinus excelsior L., Acer platanoides L., Acer campestre L. reach less than 12%. (Betula pendula Ehrh., Populus tremula L.). The average number of young growth does not exceed 2000-2500 trees per hectare where the ones of medium height prevail (50%) and small height trees reach 22%. In the considered pine stands, Quercus robur L. young growth occurs more often. There is a growth that appeared from dormant buds at the root neck after the death of the seed unit. Units of normal vitality are found only among young growth younger than 5 years old or in communities with a disturbed stand structure.

1. Introduction

The special feature of the forest-steppe landscape is the combination of two types of vegetation – forest and steppe. In the pre-anthropogenic period, the natural vegetation cover of the Central Russian forest-steppe was formed mainly by oak forests in a complex with steppes and settled meadows [1].

Forest degradation occurs on a global scale and has undesirable effects on human society and the stability of the biosphere [1,2]. The importance of the ecological and economic role that forests play in the concept of sustainable human development requires the improvement of existing and the development of new approaches to the sustainable management of natural resources [3,4]. Today's forests are heavily disturbed by logging and are small insular areas located mainly on river terraces, slopes of hollows and gullies. The need to preserve these forests, which perform anti-erosion, water protection, water-regulation and recreational functions, and to develop methods for the rational use of nature predetermine the relevance of their study.

One of the most important aspects of forest science is the study of the natural regeneration process and the factors influencing the development of undergrowth. Identifying the distribution features of broad-leaved undergrowth in forests in the forest-steppe zone and analysing its vital state makes it...
It is possible to predict the further existence of forest communities, as well as the possible directions of succession.

Comparative biometric evaluation of undergrowth using widely accepted and accepted methods leads to averaging of the results and sometimes to exclusion of natural regeneration patterns. Such analysis often leads to the conclusion that the process is random. Sometimes a burst of regeneration is explained by a favorable coincidence of ecological factors, which also introduces an element of randomness into the explanation of cause-and-effect relationships and structural and functional features of regeneration. As a consequence, the prediction, and even more so, the management of regeneration based on the results of this level of research becomes rather problematic [5,6]. The analysis of structural and functional regularities of the process is possible if the spatial and age structure of cenopopulations is studied [7].

The study of natural dynamics, the peculiarities of species, spatial and age structure, as well as the regeneration processes of natural broadleaved forests have received attention in the studies of many authors [8-10]. The main attention of the authors in these works was focused on the features of forest dynamics at the ecosystem level; studies were conducted without the use of mass age data and dendrochronological analysis of forest stand development processes. At the same time, the structure and dynamics of broadleaved forests using approaches based on detailed elaboration of the spatial and temporal continuum were virtually ignored and were covered in detail only in isolated works [11].

The vital state of the cenopopulation and features of its structure are a reflection and correspond to the capacity of the ecological niche formed [12-16]. The results of the subsequent comparative analysis of the subcenopopulation components and the assessment of the state of the cenopopulation as a whole, in turn, serve as a basis for explaining the features and patterns of the process. Importantly, the peculiarities of the spectrum structure also allow the identification of environmental factors and causes of the induction of the wave of regeneration, as well as the establishment of patterns of cenopopulation formation over time. In turn, the presence of general regularities within the process under study serves as a basis for deepening the theory of regeneration and applying its main provisions in farming practices.

The aim of this study is to characterise the features of natural regeneration of broadleaved species under the canopy of coniferous stands in forest-steppe conditions, using the example of the Belgorod region.

2. Materials and methods of the study
The study was carried out at 21 test plots in the Borisovskoye forestry and the protected “Forest on Vorskla” oak woodland in the Belgorod region (5 in the protected “Forest on Vorskla” oak woodland, 16 in the forests of the Borisovskoye forestry). Small pine woodlands (less than 600 ha) are mainly found on the floodplain terraces of the Vorskla River, less frequently on high floodplains and watersheds. On the selected plots, 20x20 m trial plots were laid, on which geobotanical descriptions of forest phytocenoses were carried out. Sample plots were placed under the canopy of mother plantations, in canopy windows and along the outer border of pine massifs.

Under the canopy of plantings, samples were laid in the presence of viable undergrowth. In order to reveal the peculiarities of the spatial structure of the undergrowth price populations outside the maternal plantations, a series of sampling plots were laid from the walls of the maternal plantation to the outer borders of the price populations. The ribbon of plots in this case was placed perpendicular to the wall of the forest area. Signs were recorded to characterise the composition and structure of the communities, using quantitative data. Tiers were distinguished in the stand with more than 25% difference between the heights of I and subsequent tiers. The species composition, number of trunks per site, average and maximum height, and stem diameter at 130 cm in height were recorded separately for each species. The age of the trees was determined using an age drill.

The annual rings on the cores were counted when processing the descriptions. When characterizing the undergrowth, the species composition and density were recorded. The ground cover was evaluated over the whole sampling area by identifying the complete species composition and evaluating the total projective cover of the grass layer and the projective cover of individual species. The illumination
conditions in the subsurface space were characterized by the indicator of the throughness of the tree canopy, which was measured using a through-flow meter. Undergrowth was counted for each species separately, by direct counting of the number of individuals in the entire sampling area, separating it by height classes: small undergrowth (0.1-0.5 m); middle undergrowth (0.5-2 m) and high undergrowth (2-5 m). The selection of these height groups was dictated by the need to compare our own data with the materials of other researchers who had previously worked in the area and had used similar height classes for the undergrowth.

The height, trunk diameter at the root neck, age, and growth of the main axis over the last three years were measured in the young trees. The order of branching, origin, presence/absence of overstory, habitus, presence of dry branches and mechanical damage were noted. With a high number of young growth in the sample area, these parameters were measured in 10 model individuals of each height class. The pine stands under consideration are represented by artificial plantations of Scots pine (*Pinus sylvestris L.*) and are distant from deciduous forests at a distance of 100 to 1000 m.

Analysis of variance was used to identify differences between samples, and the nonparametric Kruskal-Wallis test was used for groups of unequal size [17]. Methods of rank analysis of variance are based on the overall ranking of all variants (values) and comparison of the sums of the ranks for different groups. The Spearman rank correlation coefficient was used to assess correlations. A significance level of p < 0.05% was considered significant.

3. Results and discussion
In the forestry literature, the process of renewal of tree species is considered mainly from the point of view of fruiting under certain conditions, seeding, seed germination, and the appearance of self-seeding. Much attention is paid to such factors as seed quality, periodicity of fruiting, favourable soil and weather conditions, fullness of planting, tree belonging to a certain class of dominance, zoogenic influence, and the ability to form a healthy growth after cutting [11]. However, even with abundant fruiting and favourable conditions for seed germination and emergence of seedlings, it is impossible to talk about the successful renewal of this breed. The leading environmental factor limiting the development of wood young growth under the forest canopy is the lack of light. In oak, ash, hornbeam, linden, Holly and field maples, he examined the features of the growth of the aboveground axis, identified changes in the attitude to light that occur during ontogenesis, established the minimum level of PAR at which plants are still alive, but are at a sublethal level of vitality, determined the age at which, in low light, the young growth of each of these breeds passes into a quasi-senile state.

In pine plantations, we recorded young growth of 20 tree species. Such a high species diversity is facilitated by high sub-geological illumination and the weak role of pine as an edifier of the tree storey. Young growth of broad-leaved species is only 38% of the total number of young growth. 62% falls on the renewal of breeds classified as “other” (*Betula pendula, Pinus sylvestris, Populus tremula, Sorbus aucuparia, Padus avium, Acer negundo, Fraxinus pennsylvanica, Pyrus communis, Malus domestica, Salix caprea, Robinia pseudoacacia*).

In the first layer of pine trees, broad-leaved species were not noted. In the second storey, all the mentioned species are found, but the ratio of linden, ash, Norway maple and field maple is less than 12%. Oak and elm are more often present in pine stands in the second storey. The pattern of constancy looks the same for young growth: oak young growth is the most widespread, elm young growth is somewhat less common. Young growth of other species was observed in less than 30% of communities. The least common is field maple young growth (less than 10% of communities). Among the young growth of different height classes, the smallest ratio is observed in small young growth. Oak, Linden and field maple, young growth is most commonly medium. Norway maple, ash and elm young growth is usually high. In general, all breeds species have a higher ratio of young growth than adult trees (table 1). The young growth of broad-leaved species in pine forests is relatively small. Its average quantity does not exceed 2000-2500 trees per hectare and average dominates the young growth (50%) and the least small (22%).
Among the young growth of all classes of height, oak prevails. The second place is occupied by elm, and its share in the composition of the young growth increases from small to high. The share of other breeds in the young growth is very small, less than 6% of the total number of broadleaf young growth (table 2).

Table 1. Ratio of broad-leaved species and its young growth, %.

|                  | Oak | Linden | Norwaymaple | Ash | Elm | Field maple |
|------------------|-----|--------|-------------|-----|-----|-------------|
| Tree stand       | 33  | 4      | 14          | 12  | 28  | 9           |
| Young growth     | <0.5m| 57     | 6           | 9   | 7   | 16          |
|                  | 0.5-2 m | 53    | 4           | 8   | 4   | 22          |
|                  | > 2 m   | 37    | 6           | 16  | 14  | 20          |

Table 2. The young growth of broad-leaved trees in pine forests, %.

| Height class | Number of pieces / ha | Oak | Elm | Norwaymaple | Linden | Ash | Field maple |
|--------------|-----------------------|-----|-----|-------------|--------|-----|-------------|
| < 0.5 m      | 0-750                 | 62  | 24  | 6           | 6      | 2   | < 1         |
| 0.5-2 m      | 0-1500                | 54  | 40  | 3           | 2      | 1   | < 1         |
| > 2 m        | 0-800                 | 48  | 42  | 5           | < 1    | 5   | < 1         |

As for the number of seedlings of broad-leaved species, in almost all plantings of linden, ash, Holly and field maples, it is single or not at all. Elm and oak seedlings are more common, but it is also small (no more than 500 trees per hectare). The main reason for the small number of seedlings is undoubtedly the isolation of pine plantations from deciduous arrays and, consequently, the lack of a permanent source of seeds.

In the considered pine stands, the oak young growth is more common than young growth of other broad-leaved species. More than half (53%) of the young growth are medium height, 27% of the young growth are tall, and 20% of the young growth are small. Young growth classification of oak trees by the age groups revealed a significant young growth prevalence of the second group (11-20 years), which was 70% of the total number of oak young growth. The share of young growth under the age of 10 years is 24%, and over 20 years is 6%. The maximum age of the young growth is 27 years. The age of young oaks included in the stand is 20-25 years.

Seed units can be observed among the young growth. However, shoots that emerged from dormant buds at the root collar after the death of the seed unit are more common. According to O V Ryzhkov [5], the oak is able to grow from the basal part of the trunk with significant damage or complete drying of the shoots of the first year. The reasons for the death of oak young growth in pine forests are fires, damage by animals (hare, roe deer and elk), competition with fast-growing species (elm, ash-leaved maple), recreational loads (trampling, mechanical damage). In pine forests that occupy more humid ecotopes, drying of oak young growth can occur as a result of entanglement with hops. The number of small oak young growth is negatively affected by the presence of raspberry thickets in the community. In those communities where the closed raspberries canopy occupies more than 30% of the area, oak young growth is significantly less ($\chi^2 = 10.348; p = 0.001$) than in those where it occupies a smaller area.

In areas where raspberries form closed thickets, about one-meter-high, oak young growth cannot exist due to extremely low shade density. Even at the young age, oak is the least shade-tolerant of broad-leaved species. The growth rate of oak young growth in pine forests depends on the acidity and nitrogen supply of the soil. When comparing the growth rate of oak young growth in plantations that differ in acidity and nitrogen supply, significant differences were obtained between ecotopes with acidic or slightly acidic, least nitrogen-supplied soils and ecotopes with weakly acidic, sufficiently nitrogen-supplied soils (table 3). Note: the differences were found according to the Kruskal-Wallis criteria. Compared pairs of stands are following 1– acidic soils, transitional from poor to sufficiently nutrient-
supplied soils; 2 – slightly acidic soils, transitional from poor to sufficiently nutrient-supplied soils; 3 – slightly acidic, sufficiently supplied with nitrogen soils; 4 – slightly acidic, transitional from rich enough to sufficiently nitrogen-supplied soils.

**Table 3.** Differences in the growth rate of oak young growth in habitats that differ in acidity and soil nitrogen supply.

| Compared pairs of plantings | Average annual growth | Average growth over the past three years |
|-----------------------------|-----------------------|----------------------------------------|
| 1 and 2                     | $\chi^2=0.008; p=0.928$ | $\chi^2=0.521; p=0.471$ |
| 1 and 3                     | $\chi^2=37.474; p<0.001$ | $\chi^2=21.289; p<0.001$ |
| 1 and 4                     | $\chi^2=30.642; p<0.001$ | $\chi^2=30.751; p<0.001$ |
| 2 and 3                     | $\chi^2=14.486; p<0.001$ | $\chi^2=6.967; p=0.008$ |
| 2 and 4                     | $\chi^2=10.534; p=0.001$ | $\chi^2=5.564; p=0.018$ |
| 3 and 4                     | $\chi^2=0.007; p=0.935$ | $\chi^2=2.298; p=0.130$ |

Analyzing the vital state of oak young growth in pine plantations, it should be pointed out that approximately the same ratio of the number of units of normal and reduced vitality in all age groups. The share of units of normal vitality is 35-43% of the total number of oak young growth. No units of sublethal vitality were found. Units with reduced vital status grow in green-mossy pine forests (the lowest acidity points among pine stands), in communities with a large number of young growth of fast-growing species (elm and ash maple), in areas traversed by sticks, in plantations that are actively visited by the local population.

The second place in terms of the young growth abundance is occupied by the elm. It is known that its seeds can be carried by the wind over long distances. In most stands, the number of elm young growth is low, no more than 200 trees per hectare. It is slightly higher (600-2000 trees per hectare) in pine forests located in a high floodplain. There is no elm young growth in the frequently burning stands. Renewal group is dominated by the average young growth (55%), there are much more of tall young growth (34%) and least of all are small young growth (11%). The young growth is represented by units of both seed (85%) and vegetative (15%) origin. The elm young growth under 10 years old is 56%, and at the age of 10-16 years – 44% of the total number of elm young growth.

The share of other broad-leaved species accounts for only 3% of the young growth total number. In those few communities where the young growth of Bosnian maple, linden and ash is present, it is very small (less than 50 trees per hectare). English field maple in pine forests is represented by a single unit.

Bosnian maple in pine forests is renewed with seeds. Almost all the young growth is less than 10 years old. Only 9% of units were assigned to the second age group. Single units of maple over 20 years old are included in the stand. The vital state of the young growth is mostly normal (about 80% of the units), but no units of sublethal vitality were recorded.

In ash, as well as in maple, all the young growth is seminal. Almost all of it belongs to the first age group (up to 10 years), units of the 2nd age group are single. Ash trees, which are more than 15 years old, are classified as a stand by their morphometric characteristics. Among the young growth of the 1st age group, 95% of units have normal vitality, and 5% have reduced vitality.

Linden in pine forests can be renewed both by seed (55% of the total amount of linden young growth) and vegetatively (45%). Most of the units (82%) are less than 10 years old. No young growth over 20 years old has been recorded, by this age the, linden is already part of the stand. As for the classification of linden young growth according to the levels of vital status, both among the young growth under the age of 10 years, and among the young growth of older age, units of normal vitality prevail. The proportion of units with reduced vitality is about 30%. There were no units of sublethal vitality.

It should be noted that one of the reasons for the significant difference in the nature of broad-leaved young growth in pine stands is the significant diversity of the latter, mainly due to its artificial origin and strong anthropogenic disturbance.

4. Conclusion
Young growth of 20 tree species was recorded in pine plantations. Such a high species diversity is facilitated by high sub-geological illumination and the weak role of pine as an edifier of the tree storey.

Young growth of broad-leaved species is only 38% of the total number of young growth. 62% falls on the renewal of breeds classified as “other”. Among broad-leaved species, oak young growth is most abundant (21% of the total number of young growth). Slightly less (14%) young growth of elm trees (elm and elm). The young growth of Holly maple, common ash and small-leaved Linden is small (no more than 1%), and the young growth of field maple is single. All broad-leaved breeds under the age of 20 years are dominated by units of reduced vitality, older units – sublethal vitality. Instances of normal vitality are found only among young growth younger than 5 years or in communities with disturbed stand structure. In single-storey small-leaved and pine plantations units of normal vitality dominate all breeds except oak. After establishing of the reserve status in ripe and overripe stands of oak-grove “Forest on the Vorskla” is more complicated stand structure, all storey have increased the role of the Norway maple. As a result, the total number of young growth has decreased; its high-altitude structure and breed composition have changed. Currently, all the considered breeds are dominated by units of sublethal vitality among the young growth older than years. Research experience and the results obtained suggest that the wave of regeneration and pine forest stand cenopopulation with the specified age dominant is expected throughout the coniferous-broadleaf forest zone. The main condition for the formation of cenopopulation with the dominant age spectrum and successful growth and development is the presence of ecological niches corresponding to a burst of regeneration. The variation of the main biometric characteristics of pine undergrowth in the network of experimental sites will also be quite noticeable. The reason for this phenomenon is the uneven density of population fields, which can be explained, on the one hand, by the structure of the fruiting of the mother plantations, and on the other hand, by the success of the implementation of the reproductive potential of pine forests into the self-sowing category and, over time, into the undergrowth category. Taxation characteristics reflecting the structure of cenopopulations and, to a certain extent, the state of plants, against the background of density or population density, allow us to establish general patterns of structural and functional features of the formed cenopopulations and subcenopopulation fragments.

The existing difference in the average age estimate can be explained by the share of generation plants in the age spectrum of the pine forests. A characteristic feature of the processes of natural regeneration of pine forests in the territory of the Belgorod region is the coincidence in time of the dominant age spectrum of the undergrowth and young pine populations, which allows us to assume the consistency of population flows in time and their determining influence on the processes of natural regeneration. In space, the foci with the presence of regeneration processes are localized. Fragmentation of cenopopulations and subcenopopulation structures in space is logical and conditioned by the presence of niches of regeneration and correspondence of the capacity of this niche to the bioecological properties of young growth and young pines. When the capacity of the ecological niche corresponds to the bioecological characteristics of the young growth, viable cenopopulations of the thriving young growth are formed.

In the absence of such a coincidence, the attenuation of the renewal wave is observed, and the pine undergrowth, which has lost its position, gives way to a niche for the next generations, or it is replaced within the boundaries of the formed niche by species – ecological analogues. The presence of common patterns of the natural regeneration process in the zone of coniferous-broadleaved forests, as well as in the forest-steppe and steppe zone allows us to suggest the presence of a species-specific spatial and age structure of the process under consideration. Realization of the population flow is reflected in the specificity of the spatial and age mosaic of cenopopulations, which is characteristic of the species over vast geographical areas. This assumption allows not only to expand and deepen the theoretical basis of the process, but also to improve measures to support it in the restoration of native pine forests.

References
[1] Nayha A, Pelli P and Hetemaki L 2015 Services in the forest-based sector – unexplored futures. *Foresight* 17(4) 378 https://doi.org/10.1108/FS-08-2013-0034
[2] Grundel I and Dahlström M 2016 A quadruple and quintuple Helix approach to regional innovation systems in the transformation to a forestry-based bioeconomy. J. Knowl. Econ. 7 963 https://doi.org/10.1007/s13132-016-0411-7

[3] Masternak-Janu A and Masternak K 2019 Data envelopment analysis models for the assessment of efficiency of sustainable forest management in Poland. Folia Forestalia Polonica, Series A-Forestry 61(3) 182 https://doi.org/10.2478/ffp-2019-0018

[4] Bhattarai K and Conway D 2021 Forestry and Environment. In: Contemporary Environmental Problems in Nepal. Advances in Asian Human-Environmental Research (Springer, Cham) https://doi.org/10.1007/978-3-030-50168-6_8

[5] Kordrostami F, Attarod P and Abbaspour K C, Alilou H and Bozorg-Haddad O 2021 Identification of optimum afforestation areas considering sustainable management of natural resources, using geo-environmental criteria. Ecolog. Eng. 168 106259 doi:10.1016/j.ecoleng.2021.106259

[6] Kiseleva V, Stonozhenko L and Korotkov S 2020 The dynamics of forest species composition in the eastern Moscow region. Folia Forestalia Polonica. Series A 62(2) 53 doi:10.2478/ffp-2020-0007

[7] Sahara N, Nakamura T, Aizawa M and Ohkubo T 2018 Roles of bryophyte communities in germination and early growth of tree species of a subalpine deciduous broad-leaved forest established after logging in central Japan Nihon Ringakkai Shi. J. of the Japanese Forestry Society 100(4) 102 doi:10.4005/jffs.100.102

[8] Savinykh N P, Lelekovka E V and Shakleina M N 2018. About the promotion of natural restoration of Pinus sylvestris L. Theoretical and Applied Ecology 4 108 doi:10.25750/1995-4301-2018-4-108-113

[9] Chernenkova T V, Morozova O V, Belyaeva N G and Puzachenko M Y 2018 Actual organization of forest communities with broad-leaved trees in broad-leaved-coniferous zone (with Moscow region as an example). Vegetation of Russia 33 107 doi:10.31111/vegrus/2018.33.107

[10] Konashova S I, Sultanova R R, Khayretdinov A F, Gabdrahkimov K M, Konovalov V F, Rakhmatullin Z Z and Muftakhova S I 2018 Forestry and ecological aspects of the broad-leaved forest formation. J. Eng. Appl. Sci. 13 8789 doi:10.3923/jeasci.2018.8789.8795

[11] Tsaralunga V V 2003 Sanitary logging in oak forests: justification and optimization (Moscow: AT MSFU) p 240

[12] Tian Y, Jin Y, Wang Z, Su X, Hu G, Xu L and Yu M 2016 Seedling dynamics of shade tolerant and intolerant woody plants in the masson pine forests on islands of the thousand island lake. J. of Zhejiang University. Science Edition 43(4) 426-435 doi:10.3785/j.issn.1008-9497.2016.04.009

[13] Mukhitdinov N M, Karasholakova L N and Kurmanbayeva M S 2014 The number and the age structure of rare endemic species cenopopulation lonicera iliensis pojark. Life Science Journal 11(6) 459

[14] Stuart J D, Agee J K and Gara R I 1989 Lodgepole pine regeneration in anold, self-perpetuating forest in a south central Oregon. Can. J. For. Res. 191096 https://doi.org/10.1139/x89-166

[15] Long J N and Shaw J D 2005 A density management diagram for even-aged ponderosa pine stands. West J. Appl. For. 20 205

[16] Knapp B O, Wang G G, Walker J L and Hu H F 2016 Using silvicultural practices to regulate competition, resource availability, and growing conditions for Pinus palustris seedlings underplanted in Pinus taeda forests. Can. J. For. Res. 46 902 https://doi.org/10.1139/cjfr-2016-0066

[17] Kruskal W H and Wallis W W 1952 Use of Ranks in One-Criterion Variance Analysis. J. of the American Statistical Association 47(260) 583