ECOLOGICAL FEATURES OF REGENERATION OF BEECH PLANTINGS OF THE GREATER CAUCASUS

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(Received 9th Jul 2025; accepted 2nd Dec 2025)

Abstract. The ecological features of beech plantings regeneration were studied in the north-eastern part of the Greater Caucasus in Azerbaijan. Based on IPCC forecast data, the impact of climate change on forest ecosystems was analyzed on a global and national scale. The studies were conducted in 15 survey sites, where the success of beech plantings regeneration was assessed depending on relief, cenotic and soil conditions. The results showed that with an increase in the altitude of beech plantings distribution above sea level, from 830 m to 1855 m the total amount of undergrowth decreases by a factor of 2.6, and with an increase in the steepness of the slopes from 13° to 43° the total amount of undergrowth decreases by a factor of 3.3. At the same time, it was found that the maximum amount of beech undergrowth with a number of 1.66-1.64 thousand pcs/ha is formed at a density of stands of 0.41-0.48 and illumination under the canopy of 1.1-0.9 thousand lux. The study of soil conditions showed that in the middle mountain forest belt on the slopes of northern and north-western exposures, where mountain forest brown typical soils are common, the success of the regeneration of oriental beech is assessed as good, and in the lower and upper mountain belts it is weak or poor.
Keywords: *planting, success, renewal, steepness, ecological profile*

Introduction

Natural regeneration of plantations is a very important property of forest-forming species, ensuring the continuous existence of forest ecosystems. In the mountainous regions of Azerbaijan, which belong to the Greater Caucasus, the principle of continuity of forest plantings is of paramount importance, since even a short-term gap between two generations can lead to irreparable consequences. However, the process of forming a new generation of forest takes a long time and it is influenced by numerous factors, including environmental conditions.

The ecological features of successful regeneration of forest species in the north-eastern part of the Greater Caucasus, including oriental beech, are mainly associated with: growing conditions (relief elements, soil and climate); with the impact of cenotic conditions (illumination under the canopy of forest stands); with human influence (Mishnev, 1986).

Beech (*Fagus orientalis* Lipsky) plantings in the north-eastern part of the Greater Caucasus occupy about 36% of the forested area and 50% of the forest reserve (116.9 thousand hectares) of the region. They perform important ecological functions,

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2402_22212240

especially soil protection, water protection and environment-forming functions (Yakhyayev, 2007; Yakhyayev et al., 2017). The diversity of relief and soil-climatic conditions of this region has a unique effect on the regeneration of this species, which are characterized by the following indicators: mainly mountain-forest brown soils are widespread; the amount of precipitation is 550-700 mm; with an increase in altitude in the mountain slopes, the duration of the vegetation period decreases from 7.5 to 2.5 months and the sum of positive average daily temperatures above 10°C decreases from 3000°- 4000° to 1000°-1400°, and at the same time the hydrothermal coefficient increases from 1.2 to 2 and the moisture coefficient from 0.4 to 1.2 (Yakhyayev, 2022).

However, forest census data conducted in this region in 2002-2003 and 2016-2018, show that the average forest density is 0.52, with sparse forests and low-density stands covering 48.8% of the total forested area. On the other hand, the beech forests of the region are widespread on mountain slopes, where erosion processes often occur, covering large areas. As a result of forest plantings, numerous gaps, clearings and windows of various sizes were formed (Sadikhova et al., 2015).

In addition, in the forests of the region, untimely and poorly carried out thinning in the past, as well as changes in forest growth conditions in significant areas, led to a change in valuable species, including beech and Iberian oak (*Quercus iberica* Stev.) with Caucasian hornbeam (*Carpinus caucasica* A. Grossh.), field maple (*Acer campestre* L.) etc., which need to be restored with native plantings (Amirov, 1997).

At the 2018 forum "Forest Landscape Restoration in the Caucasus and Central Asia" (https://iucn.org/new/forests/201812/forest-landscape-restoration-caucasus-and-central-asia), it was noted that in Azerbaijan, out of 1.14 million hectares of forests, 593 thousand hectares will require regeneration work, especially in tugai and mountain forests. As can be seen, the country's target for afforestation - forest restoration - is 593 thousand hectares. Of this volume, the forest fund of the north-eastern part of the Greater Caucasus also accounts for a certain share of the work. On the other hand, according to the United Nations Development Programme Annual Report (2011), only 15% of the country's forests have a canopy density of 40% or more, while the remaining 85% are open or fragmented forests with a canopy density of less than 40%.

This state of the forests in the region and in the Republic as a whole is a consequence of mainly unsystematic logging carried out in the past, the results of which, according to the Global Forest Watch (2023), are presented in *Fig. 1.* This was facilitated by the use of lands of the forest fund for agricultural purposes, as well as changes in forest growth conditions in the last few decades, which was noted in the works of a number of authors (Asadov et al., 2008).

Figure 1. *According to Global Forest Watch (2023), dynamics* of cutting in Guba-Gusar *districts*

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
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In turn, studying the ecological features of the regeneration of beech forests of the Greater Caucasus, Hasanov et al. (2016) noted that in recent decades, natural regeneration has been unsatisfactory, the density of these plantings has significantly decreased, and as a result, the area of beech forests has been decreasing. They associated the changes that occurred with the growing conditions of these plantings, which are distributed mainly on the mountain slopes of the Greater Caucasus.

In another work, Pshegusov et al. (2022) modeled the ecological niches of the main forest-forming species of the Greater Caucasus to study the coexistence and patterns of formation of their modern spatial distribution. It was noted here that the geographical expression of the fundamental ecological niches of the main forest-forming species depended mainly on topographic conditions and water regime.

Yahyayev (2022), analyzing the current state of the beech forests of the Greater Caucasus, noted that, mainly due to the influence of soil and climatic factors, the growing conditions of the beech forests in the region have changed. Since the highly rugged terrain with steep mountain slopes and large amounts of annual rainfall cause the destruction of the mineral part of the soil, herbaceous and shrub vegetation, and natural forest regeneration. As a result, the conditions for the regeneration of these plantings, as well as the execution of their ecological functions, have worsened.

While studying the ongoing changes in the forests of eastern Georgia (Caucasus), Droessler and Wolff (2023) found that in beech stands (*Fagus orientalis* L.), the observed proportions of Caucasian hornbeam (*Carpinus orientalis* Mill) raise concerns about the sustainable formation of mixed-age forest ecosystems. They associated these changes with the deterioration of the growing conditions for beech forests in the region and recommended removing part of the hornbeam with thinning.

In another study (Jesus et al., 2024), the authors investigated the possibility of preserving strong old oak trees using thinning (partial pruning of branches and limbs) against the background of aridization of Southern Europe using basal area increment (BAI). The research found that the treatment carried out is a suitable management tool for maintaining strong oak tree specimens in drier climates.

As is known, modern methods and technologies of remote sensing of the Earth provide operational and long-term monitoring of spatiotemporal changes in forest stands, taking into account climatic factors (Vorobyev et al., 2024; Terekhin, 2023). In this work, based on forecast data for various IPCC (Intergovernmental Panel on Climate Change) scenarios, the impact of climate change on forest ecosystems in this region was analyzed.

In this direction, Yalcin (2012) assessed the current and potential future distribution of two economically and ecologically important tree species, Turkish pine (*Pinus brutia* Ten.) and oriental beech (*Fagus orientalis* L.), under climate change using a species distribution model (SDM). Based on the results of a group of models, it was predicted that the climatic suitable areas for these species would shift to higher altitudes and towards northern regions. Potentially suitable areas for eastern beech will be largely lost and their overall distribution will be narrower in the future.

The noted conditions and growth conditions of beech forests in this region against the background of climate change make it necessary to conduct research on the study of the issues of the success of the regeneration of these plantings depending on the relief, cenotic and soil conditions using the example of the regions. In this area, we also analyzed climate change and its impact on forest ecosystems based on forecast data from various sources around the world, including Azerbaijan.

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The existing materials on these issues date back 50 years or more, they are few in number and fragmentary. Therefore, we focused on studying these issues.

The aim of the study

Taking into account the global impact of climate change on forest ecosystems, to assess the success of the regeneration of beech plantings in the north-eastern part of the Greater Caucasus depending on relief, cenotic and soil conditions.

To achieve this, the following tasks were solved:

1. Taking into account global forecast data for the *IPCC AR6* (*2023*) scenarios, analyze the impact of climate change on forest ecosystems in this region
2. To establish the influence of relief conditions—the altitude of the terrain above sea level, the steepness and exposure of the slopes on the success of the regeneration of beech plantings in a given region
3. To establish the influence of cenotic conditions—illumination under the canopy and density of stands on the success of regeneration of beech stands in a given region
4. To establish the influence of soil conditions on the success of beech planting regeneration in this region

Objects and methods of research

Selecting sources of climate change forecast data

To analyze the impact of climate change on forest ecosystems in this region of the Republic of Azerbaijan, forecast data from the following sources were used:

- Global forecasts: IPCC AR6 (2023), Scenarios: RCP 4.5 and 8.5
- Nature Climate Change (2024)
- Caucasus Ecological Forecast (UNDP, 2023)

Geography and natural conditions of the study area

To study the ecological characteristics of the success of regeneration in 2018-2023 in beech plantings of Gusar and Guba forest regions of the Greater Caucasus, field studies were conducted. Geographic coordinates of these areas: 411311N/483247E и 422519N/482517E respectively. Using ArcGIS10.2 software, a map-scheme of the study area was developed (*Fig. 2*). The region is dominated by mountain-forest brown soils (Salayev and Babayev, 2004), the average annual temperature fluctuates between 7.3°-10.0°C, and the annual precipitation is 680-772 mm (https://azerbaijan.az/ru/related-information/17; https://method.meteorf.ru/publ/tr/tr383/htm/03.htm).

Selection of plantings and conditions for accounting for regeneration

According to the set goal, 15 survey plots (SP) with an area of 0.64-0.65 ha were established in the selected forest areas, divided into 5 sections and distributed evenly across the area (Kurbanov et al., 2016). The SP was placed in the lower, middle and upper mountain belts, where the allocation, description and processing of averaged data for the selected sections were carried out using well-known methods (Baginskiy, 2018; Ismayilov, 2011) (*Fig. 3*). Forest growth conditions on these sites were determined according to the methodological guidelines of Asadov (2008). The work also used forest management materials from Gusar and Guba forests (Forest Management, 2018).

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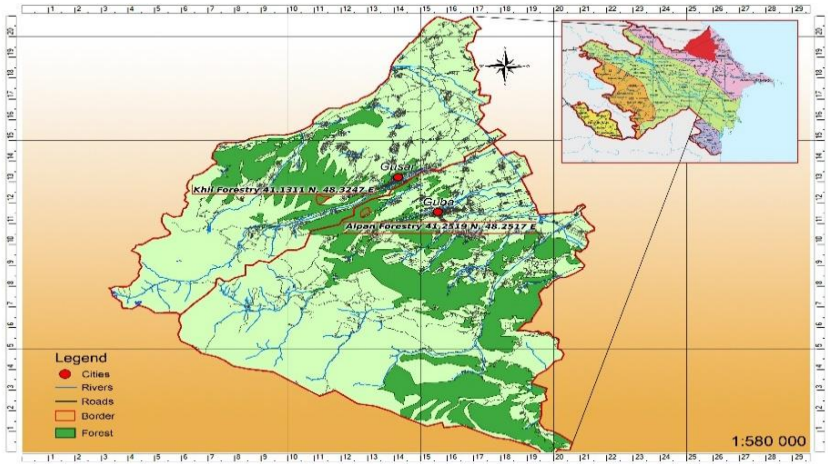

***Figure 2.** Map-scheme of Guba-Gusar districts*

***Figure 3.** Beech plantings of trial plots*

To assess the success of beech planting regeneration, the scales of Mamedov and Asadov (2010) and Kalutsky et al. (1972) were used. The young generation was counted in areas measuring (5 × 5 m), where 20 units were allocated in each SP. The success rate was determined according to the following scale: good – over 2.0 thousand pieces/ha (in terms of large undergrowth); satisfactory – 2.0-1.5 thousand pieces/ha; weak – 1.5-1.0 thousand pieces/ha; poor – less than 1.0 thousand pieces/ha. Large undergrowth was identified using conversion factors: 0.2 - undergrowth aged 2-6 years, 0.2-0.5 m in height; 0.4 - aged 6-15 years, 0.5-1.5 m in height; 1.0 - aged 16-25 years, over 1.5 m in height. Next, the undergrowth was characterized by quantity and species, and the beech growth was characterized by age, total height and root collar diameter.

The success of the regeneration of beech plantings in the north-eastern part of the Greater Caucasus was assessed taking into account the recommendation (Kurbanov et al., 2016), which stipulated that for the sustainable regeneration of beech plantings in the composition of the young generation, more than 60% or at least 1000 pieces of large undergrowth should consist of beech.

In studies, undergrowth included deciduous woody plants with a height of 0.2–6.0 m and a diameter at breast height of 0.5–6.0 cm (Shividenko, 1993).

The age of the undergrowth was determined by the annual layers of the cross-section of beech specimens cut at ground level and by the number of nodes on their stems.

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Relief conditions for the regeneration of beech plantings

In Hil forestry of Gusar district, in eight SP, the success of the regeneration of beech plantings was assessed depending on the altitude of their distribution above sea level (a.s.l.) within 830-1855 m, steepness at 13°-43° and slope exposure. The heights of the SP location above sea level were determined using GPS, and the steepness was determined using an inclinometer (*Table 1*).

In the composition of the selected plantings, beech varied from 31% to 100%. These sites were characterized by woodruff, fescue, fern, forb, subalpine forest types with forest growth conditions C_2, D_2 and D_3.

Table 1. *Characteristics of plots for the study of relief conditions*

№ SP	Plant composition	Square, P, ha	Exposition	Height a.s.l., m,	Steepness, deg.	Forest type/type of forest growing condition	Density	Aver. diameter, cm	Aver. age, year	Undergrowth composition	Number of undergrowth, pcs.
SP3	81Be19Hb	0.65	NW	1240	18	w-ruf/D_2	0.43	44	118	84Be16Hb + Ht	2878
SP2	62Be38Hb + As	0.64	NE	830	15	herb./D_2	0.47	36	95	53Be47Hb + As	3260
SP5	100Be	0.65	N	1156	13	w-ruf/D_2	0.49	32	90	86Be14Hb + Ht	4160
SP7	53BE31Hb16Mp	0.65	NE	1386	25	fescu/C_2	0.42	36	102	58Be22Hb20Mp	1920
SP12	61Be22Oo17Mpt	0.64	NW	1490	23	fern/D_3	0.51	52	134	54Be24Oo22Mpt	2170
SP14	43Be39Mpt18Oo	0.65	NE	1630	31	fescu/C	0.38	28	82	53Mpt28Be19Oo	1620
SP17	48Mpt31Be21Oo	0.64	NW	1715	37	fern/D_3	0.50	40	112	49Mpt29Oo22Be	1436
SP18	44Mpt32Be24Oo	0,65.	SE	1855	43	subal/D_2	0.41	24	72	54Mpt32Oo14Be	1250

Be – (Fagus orientalis, Lipsky); Hb – (Carpinus caucasica, A. Grossh); As – (Fraxinus excelsior, Lipsky); Mp – (Acer campestre, L); Oo – (Quercus macranthera, Fisch.et. Mey); Mpt – (Acer trautvetteri, Medv.); Ht – (Crataegus orientalis, Pall.); D, C – indicators of fertility of the soil; D – fertile; C – relatively fertile

Cenotic conditions for the restoration of beech plantations

Research into the influence of cenotic conditions on the success of planting renewal was conducted in the beech belt (1050-1180 m a. s. l.) of the Alpan forestry of Guba district. In this case, the influence of illumination on the success of planting renewal was studied depending on their completeness. For this purpose, seven SP were selected, the completeness of which varied within the range of 0.21–0.83. During the research, the degree of illumination was measured using a lux meter – TKA-PKM 09 (Russian) in windows of different sizes and planting densities (*Table 2*).

Table 2. *Characteristics of plots for the study of cenotic conditions*

№ SP	Composition of plantings	Square, SP, ha	Forest type/type of forest growing condition	Density	Composition of undergrowth	Number of undergrowth, pcs./ha.	
						Total	Beech
SP1	62Be38Hb	0.64	herb. /D_2	0.21	52Be40Hb8El	876	456
SP2	51Hb28Be21Mp+Oi	0.65	fescu. /C_2	0.32	46Be31Hb13Mp10Oi	2158	993
SP3	42Be39Hb19Mp+As	0.64	fescu. /C_2	0.41	63Be37Hb	2640	1663
SP4	54Be32Hb14Mp	0.65	herb. /D_2	0.48	65Be35Hb	2528	1643
SP5	84Be16Hb+Oi	0.64	w-ruf. /D_2	0.60	72Be28Hb	2060	1483
SP6	68Be20Hb12As	0.64	fern. /D_3	0.69	78Be22Hb	1198	934
SP7	71Be29Hb+Mp	0.65	herb./D_2	0.83	46Be38Hb16Mp	1170	538

Oi – (Quercus iberica, Stev.); El – (Ulmus scabra, Mill.)

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
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In order to obtain average data, each SP was evenly divided into 5 sections. These sections were evenly distributed in beech stands with similar forest growth conditions, in which the following forest types are common: woodruff beech forests, fescue beech forests, forest growth conditions– C_2, D_2, D_3.

At the same time, the influence of grass cover on the success of beech planting regeneration was studied at the SP, where it was assessed in percentage terms of the projective cover of a given area.

Soil conditions for the regeneration of beech plantings

During field research using the methodological recommendations of Demyanenko (2015) in the Alpan forestry of Guba district under beech plantings, common in the upper, middle and lower belts in six selected sites, soil profiles were developed, the characteristic indicators of which are presented in *Table 6.* Here, the profiles of the rhizosphere layer, granulometric composition and degree of moisture of these soils were determined (*Fig. 4*). The rhizosphere layer profiles were determined in the developed sections with the corresponding measurements, and the granulometric composition of the soils was determined using the structural catalogues of Salayev and Babayev (2004).

Figure 4. *Soil profiles in beech planting*

The moisture content of soil samples was determined under laboratory conditions in a drying chamber (Mamedov, 2007). Here, using the methodological recommendations of Terpelets and Slyusarev (2016), the levels of total humus and aqueous pH were determined in soil samples taken under laboratory conditions at the Institute of Agrochemistry and Soil Science of the MSERA. The success of the regeneration of the young generation of oriental beech was determined within a radius of 8 m around the developed soil profiles, with the obtained data being transferred to 1 ha of the accounting sites.

Mathematical data processing and analysis

In the work, data processing and analysis was carried out using the STATISTICA program +.

Results

In the work on the selected sources of forecast data, the influence of climate change factors on forest ecosystems in the world, including in the Republic of Azerbaijan, was analyzed. To do this, the data from the source Global Forecasts: IPCC AR6 (2023), Scenarios: RCP 4.5 and 8.5, which presents forecast data on changes in climate factors from 2025 to 2100. These data show that a global increase in average annual temperature from 1.2°-1.3°C in 2025 to 3.8°-4.0°C in 2100 will result in a decrease in atmospheric precipitation from 5% in 2025 to 25% in 2100.

The Nature Climate Change (2024) source presents data on the decline in forest cover worldwide depending on the increase in average annual temperature up to 2100. As can be seen, with an increase in the average annual temperature of 1.3°C in 2025, the forest cover of the region was 31%. By 2100, the average annual temperature will increase to 4.0°C, and the planet's forest cover will decrease to 20%, i.e. by 11%.

The Caucasus Ecological Forecast (UNDP, 2023) provides data on the decline in forested area and forest cover in Azerbaijan up to 2100 (*Table 3*). From the data in *Table 3* it is clear that the reduction in the forested area of the Republic in 2025 may amount to about 2%, and forest cover - 10.8%. By 2100, these figures could be 30% and 7.5%, respectively.

Table 3. *Forest cover loss*

Year	Forest square, %	Forestation, (%)	Hyrcanian forests, km^2
2025	-2	10.8	1.950
2030	-4	10.5	1.900
2050	-12	9.0	1.600
2070	-20	8.2	1.200
2100	-30	7.5	800

Source: FAO, Ministry of Ecology of Azerbaijan. https://faolex.fao.org. docs.pdf.aze163873

After analyzing the predicted data on the impact of changes in climate factors on forest ecosystems, the renewal processes of beech plantings in the north-eastern part of the Greater Caucasus were studied**.**

The results of studies to assess the success of regeneration of beech plantings depending on relief conditions, i.e. from the altitude of the area a. s. l. from 830 m to 1855 m, showed that with an increase in altitude a. s. l., the total number of undergrowth decreases by more than 2.6 times (*Table 1*). With changes in growing conditions, changes also occur in the species composition of the young generation, i.e. the number of beech undergrowth decreases from 86% at an altitude of 1156 m to 14% at an altitude of 1855 m. According to the size structure, beech undergrowth up to a height of 800-900 m above sea level is small in number and mainly consists of the large category. Small categories are found singly in more shady and humid micro-depressions. At an altitude of 1000-1100 m above sea level, an increase in the composition of medium and small-sized undergrowth is observed. This trend continues up to an altitude of 1400-1500 m a. s. l. With a subsequent increase in altitude, a decrease in small and an increase in medium and large categories of undergrowth is observed, which at an altitude of 1855 m reach up to 42%. At the same height, the proportion of oriental oak (*Quercus macranthera* Fisch. et Mey.) in the undergrowth increases to 32%, mountain maple (*Acer trautvetteri* Medv.) – to 54% (*Fig. 5*). Caucasian hornbeam (*Carpinus caucasica* A. Grossh.) makes up 47% of the undergrowth at an altitude of 830 m a. s. l., and at an altitude of 1386 m it decreases to 22%.

The results of the research showed that in this ecological profile, with an increase in the altitude a. s. l., the quantitative and dimensional characteristics of the beech under-

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2402_22212240

growth change. At the same time, the average age of undergrowth increases by approximately 2 times, the average diameter of the root collar increases by 40.2%, and its average height, on the contrary, decreases by 23% (*Table 4*).

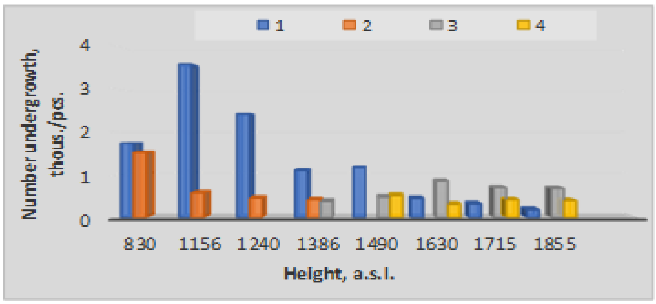

Figure 5. *Distribution of the total number of undergrowth depending on altitude above sea level: 1 – beech; 2 – hornbeam; 3 – maple; 4 – oak*

Table 4. *Changes in the quantitative and dimensional indicators of beech undergrowth*

№ SP	Height a.s.l, m	Amount of undergrowth, pcs./ha, total/beech	Middle age, years	Mean square deviation	Variation, %	Average diameter, cm	Mean square deviation	Variation, %	Average height, m	Mean square deviation	Variation, %
SP2	830	3260/1728	10.7 ± 0.8	5.81	68.8	1.12 ± 0.04	0.65	75.6	0.96 ± 0.05	0.84	76.7
SP3	1240	2878/2418	13.4 ± 1.4	9.17	60.4	1.19 ± 0.05	0.69	72.8	0.94 ± 0.04	0.81	80.5
SP5	1156	4160/3578	12.8 ± 1.1	7.88	58.6	1.23 ± 0.05	0.62	68.9	0.91 ± 0.05	0.82	73.1
SP7	1386	1920/1114	13.9 ± 1.7	9.83	63.7	1.35 ± 0.06	0.71	70.4	0.89 ± 0.04	0.77	78.6
SP12	1490	2170/1172	14.4 ± 1.8	10.04	65.2	1.33 ± 0.06	0.67	71.7	0.86 ± 0.03	0.68	85.1
SP14	1630	1620/454	16.7 ± 2.0	14.08	59.7	1.48 ± 0.05	0.66	66.2	0.82 ± 0.04	0.73	77.2
SP17	1715	1436/316	18.0 ± 2.1	14.82	57.5	1.51 ± 0.06	0.68	64.0	0.79 ± 0.04	0.63	86.5
SP18	1855	1250/175	20.4 ± 2.4	15.32	46.8	1.57 ± 0.06	0.64	62.5	0.74 ± 0.03	0.59	88.4

In the studied areas, the success of regeneration was simultaneously studied depending on the steepness within 13°-
43° degrees and the exposure of the mountain slopes. The results of the research are presented in *Figure 6.*

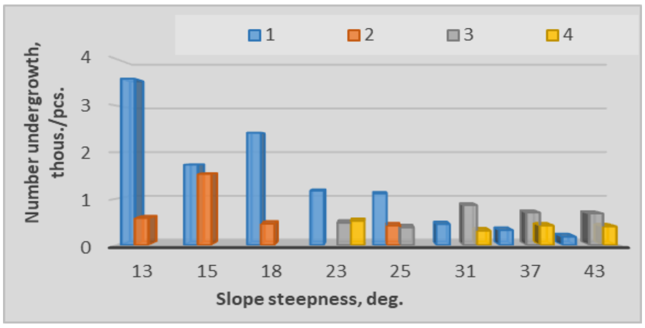

Figure 6. *Distribution of the total number of undergrowth depending on the steepness of the slopes: 1 – beech; 2 – hornbeam; 3 – maple; 4 – oak*

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From *Figure 6* it is evident that in all the survey sites, with an increase in slope steepness from 13° to 43°, the total number of undergrowth decreases by more than 3.3 times. The largest number of undergrowth with 4.16 thousand pieces/ha is observed on gentle slopes of northern exposure with a steepness of up to 15°. The smallest amount of undergrowth, 1.25 thousand pieces/ha, was noted on the steep slopes of the north-eastern exposure. On gentle slopes, beech undergrowth is found mainly in micro-depressions, covered with partially decomposed plant litter and consisting of small and medium categories. With increasing steepness of the slopes, the small category tends to decrease, and the medium and large categories tend to increase. At the same time, the share of beech in the undergrowth, depending on the composition of the stand and forest growth conditions, decreases from 3.58 thousand pieces at SP5 to 0.18 thousand pieces at SP18, i.e. up to 20 times; the remaining part of the young generation is mainly dominated by large beech specimens (Yahyayev et al., 2017).

In the studied areas, the success of regeneration of the general undergrowth and its beech part was assessed. From the data in *Table 1*, it is evident that the success of regeneration in plantations SP3 and SP5 with the participation of beech in the composition of the undergrowth of 84% and 86%, respectively, is assessed as good. In the remaining plantings, the success of regeneration was assessed as follows: on SP2 with 53% beech participation - satisfactory; on SP7 and SP12 with 58% and 54% beech participation - poor (here the number of beech undergrowth per 1 ha is small); on SP14, SP17, SP18 with 28%, 22% and 14% beech participation, respectively - poor.

As can be seen, beech stands in two studied areas have good regeneration and only in one area have satisfactory regeneration, which are widespread in the beech belt. In the remaining five areas, regeneration is weak or poor, i.e. in their ecological niche, beech stands develop unsustainably and require appropriate reforestation work (Oniskiv, 1992).

The study of the success of the regeneration of beech plantings in this region depending on the cenotic conditions, illumination under the canopy and the density of plantings was carried out in SP1-7 (*Table 2*). The results of the research are presented graphically in *Figure 7*.

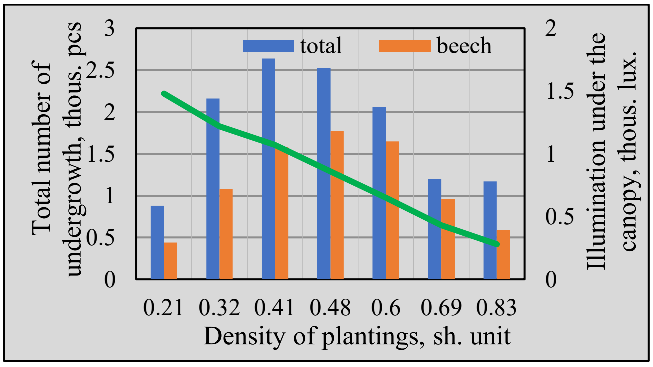

Figure 7. *Distribution of the total number and number beech undergrowth depending on the density of the plantings and the illumination under the canopy:1 – total number of undergrowth; 2 – number of beech undergrowth; 3 - degree of illumination*

As can be seen from *Figure 7*, in beech stands within the density of 0.21-0.32 and illumination under the canopy of 1.5-1.2 thousand lux, the total number of undergrowth with a number of 0.88 – 2.2 thousand pieces, including beech with 0.46 – 1.05 thousand

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2402_22212240

pieces, gradually increases. The maximum total number of undergrowth with a population of 2.53-2.64 thousand pieces is achieved with a number of 0.48-0.41 and illumination under the canopy of 1.1-0.9 thousand lux.

This trend slowly fades in stands with a density of 0.60-0.69 and under a canopy illumination of 0.4-0.6 thousand lux. At the same time, the total number of undergrowth decreases by about 2 times. In stands with a density of 0.69 and higher, illumination less than 0.4 thousand lux, a sharp decrease in the number of beech undergrowth older than 20 years is observed, and the number of small specimens increases to 90% (Yakhyayev and Khalilov, 2015).

The work simultaneously derives mathematical models reflecting the regenerative quantities of undergrowth of oriental beech depending on the relief and cenotic conditions of the habitat of this species, and also establishes correlation relationships between these parameters, which are presented below (Ribeiro and Diggle, 2001):

The number of beech undergrowth depending on the height of distribution above sea level

$$N_{a.s.l} = 0.004\ h^2 + 7.976\ h - 1716,3,\ R^2 = 0.675,\ r = -\ 0.737$$

The number of beech undergrowth depending on the steepness of the distribution slopes

$$N_{st.} = 2.322\ s^2 - 219.6\ s + 5240.6,\ R^2 = 0.727,\ r = -\ 0.883$$

The number of beech undergrowth depending on the density of the stand

$$N_d = -\ 11817\ d^2 + 12203\ d + 1567.9,\ R^2 = 0.906,\ r = -\ 0.039$$

The number of beech undergrowth depending on the illumination under the canopy

$$N_l = -\ 3249\ l^2 + 5611\ l + 792.31,\ R^2 = 0.944,\ r = -\ 0.018$$

The established correlation links show that between these parameters in stands with a density of 0.21-0.48 with the corresponding illumination there are positive, mostly close (r = 0.69-0.99), with a density of 0.60-0.83 – negatively close (r = - 0.81-0.85).

At the same time, the distribution of undergrowth by age was studied in beech stands of varying density and illumination. For a more detailed analysis of the distribution of undergrowth, its age period (1-30 years) was divided into 5-year limits (*Table 5*).

Table 5. *Distribution of the total number of undergrowth by age*

Planting density	Total number of undergrowth	Distribution of the total number of undergrowth by age intervals, years						Total, %
		1-5	6-10	11-15	16-20	21-25	26-30	
0.21	876	458	230	117	62	9	-	6.9%
0.32	2158	1287	451	233	109	56	22	17.1%
0.41	2640	1902	321	204	111	68	34	20.9%
0.48	2528	1744	338	210	113	76	47	20.1%
0.60	2060	1487	275	142	80	45	31	16.3%
0.69	1198	932	181	65	15	5	-	9.5%
0.83	1170	874	225	62	7	2	-	9.2%
Total, %	12630	8684 68.8%	2021 16.0%	1033 8.2%	497 3.8%	261 2.1%	134 1.1%	100 100

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DOI: http://dx.doi.org/10.15666/aeer/2402_22212240

As can be seen from *Table 5*, in plantings of varying density, the total number of undergrowth up to 5 years old is 68.8%. At the age of 6-10 years, the total number of undergrowth decreases by more than 4 times, this trend continues at the age of 26-30 years and the total number of young growth is only 1.1%.

During field studies, the influence of weedy herbaceous vegetation on the total number of undergrowth of beech stands of varying density and illumination was also studied. The obtained results showed that the best conditions for beech regeneration are created in stands with average density (0.40-0.50) and illumination of 1.0-0.8 lux., where 20-40% of the area is covered with herbaceous vegetation. Excessive density of grass cover negatively affects the success of beech planting regeneration.

To study the influence of soil conditions on the regeneration of beech plantings in the Alpan forestry of Guba district, 6 sections were developed in the lower, middle and upper mountain belts, the description of which is presented in *Table 6*. Here, the soil diagnostic parameters were studied, the results of which are presented below.

In section No.1*,* the morphological description of the soil consists of: B_1 - dark brown, heavy loamy, lumpy, dry, many rock fragments, thin roots, gradual transition, 0-11 cm thick; BC - grayish-brown, loamy, coarse lumpy, dry, abundant rock fragments, gradual transition, 11-26 cm thick.

The reaction of the soil solution (pH = 6.5-6.9) is neutral and increases with the depth of the profile. In this section, due to the change in the structure of the horizon from loamy in the upper to heavy loamy in the lower, an increase in the hygroscopic moisture of the soil is observed with depth. The success of beech planting regeneration in this area with 632 trees per hectare is assessed as poor (*Table 6*) (Mamedov, 2009).

In section No. 2, the morphological description of the soil consists of: A_0 - a sod layer 0-5 cm thick, consisting of varying degrees of dissected forest litter; A - a dark brown, light loamy, nutty-lumpy layer, gradual transition, 5-17 cm thick; B - a dark brown, light loamy, lumpy layer, rock fragments, gradual transition, 17-25 cm thick; B_1 - a grayish-brown layer, heavy loamy granular-lumpy, gradual transition with a thickness of 25-38 cm; BC - a grayish layer, fragments of clay shale with fine earth, 38-50 cm thick,

The reaction of the soil solution (pH = 5.7-6.8) is slightly acidic or neutral and increases with depth of the profile. In this section, due to the change in the structure of the horizon from light loamy in the upper to heavy loamy in horizon B_1, an increase (4.15-5.95%) and a decrease in the hygroscopic moisture of the soil are observed in the last horizon. Here, the success of regeneration of the beech part of the planting with 1245 pcs/ha of undergrowth is assessed as weak (*Table 6*).

In section No.3 the description of the horizons consists of: A_0 - forest litter with a thickness of 0-6 cm, consisting of beech leaves, hornbeam, in places fungal hyphae, the lower layer is mixed with soil; A_1 - a layer of dark blackish color, coarse-grained, 6-13 cm thick; B - a layer of brown-grayish color, light loamy, coarse-lumpy, 13-25 cm thick; BC - a layer of light brown color, coarse-grained-lumpy, loamy, 25-41 cm thick.

The reaction of the soil solution (pH = 6.8-7.5) is neutral; humus gradually decreases with depth of the profile from 5.64% to 4.21%. Here, due to the change in the structure of the horizon from light loamy in the upper to loamy in the lower, the hygroscopic moisture of the soil first decreases to 3.56%, then increases to 4.05%. The success of beech regeneration in this area with 2578 pcs/ha was assessed as good (*Table 6*).

The description of the soil of section No.4 consisted of: A_0 – forest litter with a thickness of 0-4 cm, consisting of litter residues, here browned soft biomass is formed; A_1 – a layer of dark brown color with brownish shades, granular-lumpy, nutty-lumpy with

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small rubble and large sand grains, medium and heavy loamy with multi-plant roots, 4-12 cm thick; B – a layer of brown-grayish color with a predominantly light grayish shade. Thin humus layers are observed in the intervals. The structure is lumpy, hard, heavy and medium loamy, 12-28 cm thick; BC – a layer mainly brown and brownish-grayish brown in color, hard, rubble-like. The structure is coarse-grained and lumpy, medium loamy with sand, 28-45 cm thick.

The reaction of the soil solution (pH = 5.9-7.2) is slightly alkaline or neutral and increases with depth of the profile. Here, structural changes in the horizons are accompanied by corresponding changes: the hygroscopic moisture content of the soil increases from 3.8% to 4.23% in depth, and the humus content decreases from 2.8% to 1.11%. The success of beech regeneration with 1532 pcs/ha in this area was assessed as satisfactory (*Table 6*).

Table 6. *Characteristics of plot with developed soil profiles*

No. soil section	Characteristics of the site with soil sections	Degree of washout	Genetic horizon	Horizon power, cm	pH.mv	Humus, %	Hygroscopic humidity, %	Number of undergrowth pcs./ha	
								Total	Beech
1	Maple-hornbeam-beech forest (65Be23Mpt12Hb, density 0.42, mid. age 66 years), NE slope with a steepness 29°, a.s.l. 1606 m	Heavily washed	B_1	0-11	6.5	1.10	2.66	962	632
			BC	11-26	6.9	0.83	3.13		
2	Oak-hornbeam-beech forest (76Be16Oo8Hb, density 0.65, mid. age 92 years), NE slope with a steepness 18°, a.s.l. 1540 m	Unwashed	A_0	0-5					
			A_1	5-17	5.7	6.71	4.15	1686	1245
			B	17-25	4.9	5.50	4.54		
			B_1	25-38	6.1	4.65	5.95		
			BC	38-50	6.8	4.10	5.34		
3	Hornbeam-beech forest (68Be32Hb, density 0.62, mid. age 100 years), NW slope with a steepness 20°, a.s.l. 1220 m	Unwashed	A_0	0-6					
			A_1	6-13	6.8	5.64	3.88	3943	2578
			B	13-25	7.3	4.69	3.56		
			BC	25-41	7.5	4.21	4.05		
4	Hornbeam-beech forest (54Be46Hb, density 0.41, mid. age 84 years), N slope with a steepness 28°, a.s.l 1140 m	Medium washed	A_0	0-4					
			A_1	4-12	5.9	2.08	3.80	2287	1532
			B	12-28	6.5	1.61	3.91		
			BC	28-45	7.2	1.11	4.23		
5	Beech-oak-hornbeam forest (50Hb36Be14Oi, density 0.50, mid. age 74 years), SE slope with a steepness 35°, a.s.l. 884 m	Weak washed	A_0	0-5					
			A_1	5-16	7.4	3.80	4.46	2490	1321
			B	16-34	7.3	2.78	3.96		
			B_1	34-55	6.7	2.20	3.71		
			BC	55-76	5.4	1.84	3.11		
6	Beech-oak-hornbeam forest (64Hb26Be10Oi, density 0.44, mid. age 88 years), SE slope with a steepness 27°, a.s.l. 778 m	Medium washed	A_0	0-4					
			A_1	4-11	6.3	1.98	3.87	1861	1196
			B	11-26	6.6	1.47	4.31		
			BC	26-44	7.4	1.29	4.63		

Description of soil of section No. 5 consisted of: A_0 – a layer with a thickness of 0-5 cm, consisting of weakly dissected and partially decayed forest litter; A_1 – a layer of dark brown color with cinnamon shades, nutty, heavy loamy, hardish, with many woody roots, 5-16 m thick; B – a layer of dark brown color, coarsely lumpy, light loamy, compacted, moist, with many woody roots, 16-34 cm thick; B_1 – a layer of brown color, fine-grained-lumpy, hardish, heavy loamy, easily moistened, 34-55 cm thick; BC – light

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DOI: http://dx.doi.org/10.15666/aeer/2402_22212240

brown loamy, the structure is similar to the previous ones, the accumulation of carbonates is somewhat smaller, roots are not found, the moisture level is average, the transition is clear, 55-76 cm thick.

The reaction of the soil solution (pH = 7.4-6.7) is slightly alkaline or neutral. Due to changes in the structure of horizons along the depth of the profile, changes in the pH value, humus content and hygroscopic moisture of the soil are observed. In this area, the success of the regeneration of the beech part of the planting (1321 pcs/ha) was assessed as weak (*Table 6*) (Babayev, 2006).

Description of soil section No. 6*:* A_0 – forest litter 0-4 cm thick, consisting of hornbeam and beech leaves, fungal hyphae in places, many rock fragments, thin roots; A_1 – dark brown layer, coarse-grained, 4-11 cm thick; B – brown-grayish layer, medium loamy, coarsely lumpy, 11-26 cm thick; BC – brown layer, coarse-grained-lumpy, light loamy, 26-44 cm thick.

The reaction of the soil solution (pH = 6.3-7.4) is slightly alkaline or neutral and increases with depth of the profile. Here, due to the change in the structure of the horizons, from medium loamy to light loamy, an increase in hygroscopic moisture and a decrease in humus content with depth are observed. Here, the success of beech regeneration (1196 pcs/ha of undergrowth) is assessed as weak (*Table 6*).

Discussion

Analyzing global forecasts of IPCC AR6 (2023), it was found that by 2100, due to fires and pests, the forest area of the northern hemisphere is expected to decrease by 20-40%, in mountain forests their shift along altitudinal belts may be 200-300 m upward, at the same time with warming by +1.5°C, according to forecasts of Nature Climate Change (2024) due to droughts, forest productivity will decrease by 15%. In the conditions of Azerbaijan, according to the Caucasus Ecological Forecast (UNDP, 2023), by 2100 the temperature increase will be 2.5-3.0°C, and precipitation will decrease by 10-20%.

After analyzing the predicted data on the impact of climate change in the future on forest ecosystems, it is possible to study the success of the regeneration of the oriental beech, common in the north-eastern part of the Greater Caucasus.

When studying the influence of relief conditions, i.e. the height of distribution above sea level on the regeneration of oriental beech, it was established that within the range of 800-1200 m above sea level, beech undergrowth increases, reaching a maximum quantity of up to 2418 pcs/ha at 1156 m above sea level. Under these conditions, the success of beech regeneration is assessed as good. With a subsequent increase in altitude to 1855 m a. s. l., the number of beech undergrowth decreases to 175 pcs/ha, i.e. 13.8 times; under these conditions, the success of beech regeneration is assessed as poor. At the same time, changes in the age and size of beech undergrowth were studied depending on the height of distribution of beech stands. It was found that with an increase in altitude from 830 m to 1855 m a. s. l., the age and diameter of beech undergrowth increases by 41% and 91%, respectively, while their height, on the contrary, decreases by 23%.

Khabagin (2023), studying the shoot and fruit traits of the subalpine *Fagus orientalis* from the Eastern and Western Caucasus, also found the greatest size variability in the Eastern Caucasus population, associated with climatic conditions in the Western Caucasus, which are shorter by almost a month during the vegetation period.

In another work (Akram, 2023), Iranian specialists, studying the features of geometric morphology of the leaves of beech trees (*Fagus orientalis* L.), distributed at different

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altitudes, also found that with increasing altitude a. s. l., these leaf features tend to decrease.

During the research conducted in this region, the following features of the regeneration of oriental beech were established:

- in the upper mountain zone (1600 m a. s. l. and above) the success of the regeneration of oriental beech in terms of quantity and condition is assessed as unsatisfactory. In this ecological profile, the amount of beech undergrowth decreases to 20%, and in terms of condition, the undergrowth often includes bent, curved, and shorter specimens;
- in all zones around fallen and cut down beech trees or groups of trees up to 3 years old, small undergrowth makes up to 80%, in the same places 20 or more years old, the number of small undergrowth decreases to 10%;
- depending on forest growth conditions, beech specimens spread more actively at altitudes of 800 m a. s. l. and higher, i.e. they migrate upwards to more humid areas.

The regeneration responses to growing conditions of oriental beech were also noted in the work of Mustafa Yilmaz (2010). Here, the author, comparing isolated relict forests of oriental beech (*Fagus orientalis* L.), distributed in the northern and southern regions of Turkey, found that these populations differ somewhat in distribution, health status and response to climate change. The distribution of beech forests in southern Turkey begins at about 1000 m, in contrast to the northern distribution, which begins at about 150-200 m. The author of this situation attributed it to the fact that in the south of Turkey the average temperature is higher, and the summer drought occurs due to irregular precipitation, as a result of which in recent decades some of the beech forests have been shedding their leaves in the summer in response to severe drought.

During a study of the success of oriental beech regeneration in this region, it was found that the quantity and condition of the undergrowth depend to a large extent on the steepness and aspect of the slope. Since on slopes with a steepness of up to 13°-15° in northern exposures the number of beech undergrowth increases, reaching up to 3578 pcs/ha at 1156 m a. s. l., and the success of regeneration in these conditions is assessed as good. With increasing slope steepness within 23° - 43° degrees, the number of undergrowth in mainly southern exposures decreases to 175 pcs/ha at 1855 m altitude. At the same time, the number of undergrowth in all plantings is sharply decreasing, which was associated with the deterioration of soil and hydrological conditions in the habitat of beech plantings. The greatest number of undergrowth is observed on gentle slopes with a steepness of up to 20° of northern and northwestern exposure; under these conditions, the success of regeneration is assessed as good or satisfactory. On the slopes of southern and south-eastern exposure with a steepness of 25° or more, the number of beech undergrowth decreases significantly. Here, the success of regeneration is assessed as weak to poor (Mamedov and Khalilov, 2002).

The results obtained in the study of the success of the regeneration of beech plantings in this region depending on the cenotic conditions, illumination under the canopy and the density of the plantings show that in sparse and low-density plantings (0.21-0.32) beech seedlings and undergrowth are mainly found under individual trees and groups of trees remaining in the plantings. The reason for this is increased insolation, which leads to rapid drying of the litter and soil in open areas, as a result of which not only self-seeding dies, but also seeds that do not find favorable conditions for germination. At an average

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2402_22212240

density, the undergrowth is located in clumps (groups) in the gaps of the canopy, formed as a result of the fallen of stunted trees or the cutting down of individual trees. In stands of all densities, the number of undergrowth decreases sharply with age, which is associated with the size and timing of canopy closure in forest stands. At a density of 0.4-0.5 and illumination of 1.2-0.9 thousand lux, the maximum number of beech undergrowth was detected; with a further increase in the density of stands to 0.7 and higher, the illumination under the canopy and, accordingly, the number of undergrowth sharply decreases. The data obtained by us are confirmed by the findings of other researchers that beech stands are better restored in (0.4-0.5) dense stands with a density of 0.55-0.65 (Hasanov et al., 2016).

It is known that, all other conditions being equal, under the canopy of plantings of varying density (crown density), light conditions are created, with a change in which all other factors associated with the regeneration process change dramatically. The following biological features of the oriental beech also play an important role in this process: the discrepancy between the crown density, which exceeds the stand density by 0.1-0.3 units; the mosaic arrangement of leaves, which creates a dense tree crown that lets in very little light (Yakhyayev, 2022).

In this work, the developed mathematical models expressing the dependence of the renewable number of beech on the relief conditions of growth of this species are characterized by fairly high negative values ($r = -0.737$; -0.833) of the correlation coefficient, and with the cenotic conditions of growth - very weak negative values ($r = -0.039$; -0.018). Here, the very weak relationship is explained by large, sharply different differences between the values of the correlating parameters.

During the research it was also revealed that intensive loss of self-seeding and small undergrowth is observed in the plantings, reaching about 31% at the age of up to 5 years, 84% at the age of up to 10 years, and 96% at the age of up to 20 years (*Table 4*). This is explained by the biological properties of the oriental beech, since this species successfully regenerates in conditions of sufficiently high air and soil humidity. On the other hand, self-seeding and undergrowth appearing under the canopy, competing with the root systems of the parent trees, constantly experience a lack of moisture in the soil.

As a result, it can be noted that in the north-eastern part of the Greater Caucasus, in conditions of complex rugged relief on slopes of varying steepness and exposure under beech and beech-hornbeam plantings, mountain-forest brown soils are widespread, and their most developed profile is found under closed beech plantings. Here, these soils, depending on human activity and soil-forming factors, are in different stages of their development.

At the lower boundary of the forest zone, when the forest is destroyed, the soil undergoes a stage of steppe formation, which leads to a change in its structure: from nutty it changes to granular, and the upper soil horizons acquire a dark color. In the northeastern part of the Greater Caucasus under study, the natural course of soil formation has been sharply altered in a number of cases due to human economic activity and the development of erosion and washout. Under these soil conditions, the success of oriental beech regeneration is estimated to range from poor to weak (at 632 pcs/ha and 1245 pcs/ha, respectively) (Mamedov, 2004).

In the middle mountain-forest belt on the slopes of the northern and north-western exposure of this region, mountain-forest brown typical soils are observed under beech plantings. Here, due to the narrowing of the beech forest zone, their area is decreasing. Typically, these soils have forest litter on the surface (4-5 cm), due to which they have a

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DOI: http://dx.doi.org/10.15666/aeer/2402_22212240

fairly high water permeability and surface runoff is formed insignificantly. In this ecological profile, the success of beech regeneration is assessed from good to satisfactory (at 2578 pcs/ha and 1532 pcs/ha)

In the upper mountain forest belt on the slopes of the northern and north-eastern exposures of this region, under beech-hornbeam and beech-maple forests, mountain forest brown poorly developed soils are mainly widespread. Here, as a result of erosion, the entire soil layer has been washed away in places and outcrops of parent rocks can be seen on the surface. In these conditions, the regeneration of plantings, including oriental beech, where damaged and a few large specimens are found on steep slopes and on gorge terraces. In these soil conditions, the success of beech regeneration is assessed as weak (at 1321 pcs/ha and 1190 pcs/ha) (Babayev, 2006).

Recommendations

Taking into account the results of the global impact of climate change on forest ecosystems on a regional scale, for the natural regeneration of oriental beech, which is the main forest species in this region, the conservation of its distribution areas and the preservation of biodiversity and ecological balance in the forest ecosystem of the north-eastern part of the Greater Caucasus, it is recommended to: increase research and observation work on the regeneration process along the distribution belts of this species, timely cutting, care mainly due to secondary species (hornbeam, maple, elm), in low-density stands, increase work to promote natural regeneration.

Conclusion

Based on the results of the research, the following conclusions were made:

- Against the backdrop of the global impact of climate change on forest ecosystems, it has been revealed that by 2100, the forested area in Azerbaijan will decrease to 30%, and forest cover will decrease to 7.5%.
- It has been established that with an increase in the altitude of the terrain a. s. l. from 830 m to 1855 m, the total number undergrowth decreases by more than 2.6 times. In the species composition of the young generation, the number of beech undergrowth also decreases from 86% at an altitude of 1156 m to 14% at an altitude of 1855 m, while its age and size characteristics change. The success of the regeneration of oriental beech has been noted within the altitude range of 900-1300 m above sea level, which is assessed as good, partly satisfactory.
- It has been established that with an increase in slope steepness from 13° to 43°, the total number of undergrowth decreases by more than 3.3 times. The largest amount of beech undergrowth with 3.58 thousand pcs/ha is observed on slopes with a steepness of 13° in the northern exposure. Successful regeneration of oriental beech, mainly with a good assessment, was noted on slopes with northern and north-western exposures with a steepness of up to 20°.
- It has been established that in beech stands within the range of density of 0.21-0.32 and illumination under the canopy of 1.5-1.2 thousand lux, the total number of under-growth with a number of 0.88-2.16 thousand pieces gradually increases. The maximum amount of beech undergrowth with a number of 1.64-1.66 thousand pieces is achieved with a density of 0.48-0.41 and illumination under the canopy of 1.1-0.9 thousand lux, the success of the regeneration of which is estimated as

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satisfactory. This trend slowly fades in stands with a density of 0.60-0.69 and illumination under the canopy of 0.4-0.6 thousand lux.

- It has been established that the best soil conditions are noted in the middle mountain-forest belt on the slopes of the northern and north-western exposure of this region, where mountain-forest brown typical soils are widespread under beech plantings. In this ecological profile, the success of regeneration of oriental beech is assessed as good (with 2578 pcs/ha), partly satisfactory (with 1532 pcs/ha). In the upper and lower mountain forest belts, the success of regeneration is assessed as weak or poor.

Acknowledgments. The authors are grateful to Shakhbal Magsudov, a researcher at the Guba branch of the Shahdag National Park, for his assistance in selecting survey sites, and to the forestry staff for their practical assistance in conducting research and providing materials for the planning projects of these farms.

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