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The regeneration of Oriental beech (*Fagus orientalis* Lipsky) share in the secondary hornbeam stands using the complex cutting

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Abstract: In the paper, the results of the complex cuttings were presented in the secondary hornbeam stands with the aim of regenerating the natural beech stands in the northern regions of Azerbaijan. For this purpose, three complex cutting procedures were carried out with a recurrence at 5 and 10 years in four sites of the secondary hornbeam stands in the northern regions. The experimental plots were characterised with: a stand density of 0.5–0.7, the age of the forest stands of 60–130 years, undergrowth of 12–25 years, a stand volume of 130–200 $m^3 \cdot ha^{-1}$, the beech percentage in the composition of stands of 17–28%, hornbeam 62–79% spread over the southern and northern slopes of the mountains. As a result of the complex cuttings, the share of beech trees in the composition of the parent stands increased 2.2–3.0 times. During cutting, the share of beech trees, as a part of undergrowth, increased 3.8–4.3 times. Based on the data, mathematical models were established reflecting the dynamics of the numbers of the undergrowth and the total stand volume of the forest stands depending on the participation percentage of beech trees in the parent stand.

Keywords: regeneration; forestry; undergrowth; selective cutting; thinning

Beech (*Fagus orientalis* Lipsky) forests of the northern regions of Azerbaijan occupy about 36% of the forest covered area, which have huge silvicultural and ecological significance for the whole region. As a result of clear cutting, forced-selective logging, and under the influence of other anthropogenic influences that have been carried out in these forests, the oak (*Quercus iberica* Stev.) and beech were replaced by two hornbeam species (*Carpinus caucasica* A. Grossh., *Carpinus orientalis* Mill.) and other low-value woody species, mainly in the lower (up to 600 m) and middle (600–1 400 m) mountain belts. These changes are noted from 7 to 53% of the forest cover areas, mainly in the oak and beech forests. Simultaneously, the stand density of these forests decreased to 0.1–0.3 and the stand volume declined to 50–100 $m^3 \cdot ha^{-1}$ (Amirov 1993; Yakhyaev 2014).

According to many estimates, the subsequent native process of replacing the secondary hornbeam stands by beech ones takes 80–240 years (Sukachev et al. 1957; Huseynov 1975; Marian 1981; Ananyev, Moshnikov 2013). In the 19th and 20th centuries, after cutting down the beech forests in Europe for firewood, their regeneration process lasted 90–140 years as well (Jorg, Orjan 2010).

To accelerate the native process of replacing of the secondary hornbeam stands by beech ones, we

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need targeted forestry measures. In spite of the fact that the mature part of the hornbeam stands is constantly increasing, there is a lower need for the production of hornbeams. On the other hand, due to the increase in the composition of the coppice and bushy trees, the marketability of the stand volume of the secondary species decreases. By remaining under the canopy for a long time, the beech gradually loses its ability to regenerate naturally. All this requires urgent actions to regenerate the forest formations of valuable tree species (oak, maple, beech), especially the beech.

In the regenerated native beech stands of the former forest areas increase of the beech attained through the increasing percentage of beech in the composition of the parent stand and the formation of highly productive forest stands called for complex cutting, which has been most effective in the mountain forests of the Greater Caucasus (Melekhov 1989; Koval, Solntsev 1992). During the complex cutting procedure, selective cutting and thinning are carried out simultaneously in the same area. In the first case, the ripe and overripe part is cut down, and in the second case, the forest stands are cared for by the young generation. The thinning process is carried out for valuable breeds ranging from release cutting to salvage cutting, mainly due to the cutting of minor species.

The purpose of the research was to study the regeneration dynamics of the beech regeneration in the secondary hornbeam stands of Azerbaijan by using complex cutting. The following tasks were addressed in the work: Assess the effectiveness of complex cutting in the recovery process of native beech stands. (*i*) Establish basic criteria for the successful regeneration of native beech stands depending on their place of growth. (*ii*) Establishment of mathematical models and recommendations for the economical application of the regeneration of native beech stands.

MATERIAL AND METHODS

The research was carried out on the forests of the Guba (41°21'N, 48°30'E) and Gusar (41°25'N, 48°26'E) regions of Azerbaijan. Mountain-forest brown soils are mainly distributed in the research area. Here, the average annual temperature varies between 8.6–11.9 °C, the annual precipitation is 570–694 mm. Plots (0.49–0.64 ha) were established according to the requirements of the regional standards (OST 56-69-83:1983) and the methodical instructions of Makhatadze and Popov (1965) in fescue and herbaceous forest types with a stand density of 0.54–0.73 (Table 1).

Since establishing the plots, repeated measurements have been carried out before and after cutting in 1993, 1998 and 2008, and the last inventory, without cutting, was conducted in 2016 jointly with the staff of our department and the Institute of Forestry of the Republic. During all the years of investigation, we carried out an entire inventory of the trees with a diameter more than 6.1 cm at a diameter at breast height (DBH) of 1.3 m (Anuchin 1982; Sennov 1984). The regeneration processes in the cutting areas were studied according to the standards (Huseynov 1975) and methodological instructions (Pobedinsky 1966) on the experimental sites with a size of 2 × 5 m. These standards evaluate the regeneration processes of the seedlings in the experimental sites. In each plot, 15–20 experimental sites were evenly placed. Here, the total number of seedlings with the allocation of its beech part was calculated, and also the height of the beech undergrowth was measured.

To process the plots in the forest stands, a selective cutting was used with a weak (5–15%) and moderate (moderately high) (16–25%) intensity, with a repeatability of 5 and 10 years (Vasiliev 1971; Cutting rules 1999; Ushatin, Mamonov 2008). The thinning was carried out simultaneously, beginning with the release cutting in the composition of the undergrowth and ending with salvage cutting in the middle-aged stands in the second tree layer (Table 2).

After the completion of all of the complex cutting methods, the best and largest beech trees and the other valuable tree species of the parent stand, as well as those from the younger generation were left to grow. They included secondary species, which were desirable to leave them in the composition of the future forests to form mixed forests with an optimal stand density. The harvesting works were carried out with the technical assistance in the Guba and Gusar forests using gasoline-powered saws, horse transportation (in less accessible places) and a TDT-55 tractor (Onega Tractor Factory, Russia). The cuttings took place in autumn (September–October). At the end of each procedure, the degree of damage to the stands was determined by the number of damaged trees and the undergrowth in accordance with Melekhov's recommendations (Melekhov 1989).

After cleaning the cutting site from the felling residue as a measure to promote reforestation, regen-

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Table 1. Characteristics of the objects at the time of establishing the plots (1993)

Plot No.	Forest stand				Undergrowth				Altitude, aspect and slope	Forest type/ forest growing conditions	Site index	Stand density	Stand volume ($m^3.ha^{-1}$)
	composition by stand volume	average			composition by number	average		number per ha					
		age (year)	diameter (cm)	height (m)		age (year)	height (m)						
Guba forest													
P-1	78Hb19Be3Mp	90	28	21	90Hb8Be2Mp	17	1.5	3 500	1 070/N-25°	Herb/D_2	II	0.7	150
P-2	62Hb28Be10Mp	130	36	23	73Hb22Be5Mp	25	1.8	4 200	1 136/SW-28°	Fescue/C_2	III	0.5	130
Gusar forest													
P-3	68Hb23Be9O	60	24	19	77Hb19Be4O	12	1.0	1 160	956/N-14°	Herb/D_3	II	0.7	200
P-4	79Hb17Be4Ac	80	32	20	70Hb27Be3Ac	15	1.3	2 340	844/SE-23°	Herb/C_2	III	0.6	190

Hb – hornbeam (*Carpinus caucasica* A. Grossh.); Be – beech (*Fagus orientalis* Lipsky); Mp – maple (*Fraxinus excelsior* Lipsky); O – oak (*Quercus iberica* Stev.); Ac – acer (*Acer platanoides* Lipsky); Herb – herbage; D, C – indicators of fertility of the soil; D – fertile; C – relatively fertile, I, II – bonitet classification

eration sites with dimensions of 1 × 1 and 1 × 2 m were partially created around the beech seed trees at a distance of up to 25 m. At the same time, the grass cover and litter were removed from the soil surface and it was loosened up to a depth of 6–7 cm. Over the next 5 years, 3–4 treatments on the regeneration sites were carried out. Inside these sites, the soil was weeded, the grass and the seedlings of the secondary species were removed, and bushes, tall grasses and secondary species of woody plants were cut down around the sites at a distance of 1–1.5 m.

RESULTS

In the first complex cutting procedure at plots P-1 and P-3, a selective cutting with an intensity of 21.3% and 31.0% was applied (Table 2), respectively. The removed trees from the upper tree layer mainly consisted of hornbeams, the only beeches that were cut were the damaged ones. As a result, the percentage of beech trees in the upper level increased by 26.3% and 21.7% in the stand volume, respectively. The damage to the stands was 9.6% and 7.2%, respectively.

In the beginning of the experimental cutting in the forest stands' undergrowth at P-1 and P-3, we observed an undergrowth with a height 3.5–5.5 m and 1.0–2.5 m, respectively. In the undergrowth with 1.0–2.5 m height, we found a mosaic density and the gradualness of the entire canopy that mainly consisted of hornbeam. The thinning of all the young generations of beech trees and other species was carried out with an intensity of 35% and 28%, respectively, mainly by the top method with a selection from the undergrowth with a height of 3.5–5.5 m of the fast-growing species (hornbeam, etc.), and by the combined method, releasing the beech from the oppressive effect of the hornbeam part of the canopy in the undergrowth with a height of 1.0–2.5 m. Due to the removal of the hornbeam, the participation percentage of the beech trees in the composition of the undergrowth of these forest stands increased by 23.6% and 10.7% (Table 2), respectively. At the end of the first of complex cutting procedures, 114 and 128 "regeneration sites" per hectare were created around the beech seed trees.

During the second selective cutting procedure, it was revealed that the forest stands at P-1 and P-3 had not fully recovered from the past period (in the quantity before cutting, 88% and 79% in the stand volume and 91% and 80% in the number of

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Table 2. Dynamics of the inventory indicators in the secondary hornbeam stands, by application of the complex cutting

Plot No.	Period of observations		For the forest stands				For the undergrowth			
			composition, by stand volume	stand volume ($m^3 \cdot ha^{-1}$)	intensity cutting, by stand volume (%)	increment of current ($m^3 \cdot ha^{-1}$)	composition, by number	intensity cutting, by number (%)	No. of undergrowth ($pcs \cdot ha^{-1}$) general	No. of undergrowth ($pcs \cdot ha^{-1}$) beech
P-1	1993	before cutting	78Hb19Be3Mp	150	–	–	90Hb8Be2Mp	–	3 500	280
		after cutting	72Hb24Be3Mp	118	21.3	–	86Hb11Be3Mp	35.0	2 275	248
	1998	before cutting	70Hb26Be4Mp	132	–	2.80	81Hb16Be3Mp	–	2 684	424
		after cutting	65Hb31Be4Mp	114	13.6	–	78Hb18Be4Mp	18.6	2 186	378
	2008	before cutting	62Hb34Be4Mp	163	–	3.90	75Hb21Be4Mp	–	3 360	705
		after cutting	54Hb41Be5Mp	133	18.4	–	71Hb26Be3Mp	27.5	2 437	634
	2016	without cutting	49Be46Hb5Mp	174	–	5.13	62Hb34Be4Mp	–	3 144	1 061
P-2	1993	before cutting	62Hb28Be10Mp	130	–	–	73Hb22Be5Mp	–	4 200	924
		after cutting	58Hb32Be10Mp	111	14.6	–	69Hb25Be6Mp		3 180	777
	1998	before cutting	57Hb32Be11Mp	127	–	3.20	66Hb28Be6Mp	–	3 870	1 098
		after cutting	52Hb36Be12Mp	105	17.3	–	65Hb30Be5Mp		3 266	962
	2008	before cutting	54Hb34Be12Mp	142	–	3.70	66Hb28Be6Mp	–	4 070	1 118
		after cutting	46Hb44Be10Mp	113	20.4	–	57Hb36Be7Mp	32.9	2 730	992
	2016	without cutting	47Be42Hb11Mp	157	–	5.5	53Hb39Be8Mp	–	3 560	1 386
P-3	1993	before cutting	68Hb23Be9O	200	–	–	77Hb19Be4O	–	1 160	221
		after cutting	61Hb28Be11O	138	31.0	–	73Hb23Be4O	28.3	832	192
	1998	before cutting	57Hb 31Be12O	159	–	4.20	63Hb33Be4O	–	1 134	383
		after cutting	52Hb36Be13O	135	20.1	–	58Hb37Be5O	19.6	912	336
	2008	before cutting	49Hb37Be14O	191	–	5.6	52Hb43Be5O	–	1 590	690
		after cutting	44Be42Hb14O	144	24.6	–	50Hb46Be4O	15.5	1 344	626
	2016	without cutting	52Be33Hb15O	193	–	6.13	52Be43Hb5O	–	1 840	954
P-4	1993	before cutting	79Hb17Be4Ac	190	–	–	70Hb27Be3Ac	–	2 340	632
		after cutting	75Hb20Be5Ac	152	20.0	–	65Hb31Be4Ac	26.5	1 720	533
	1998	before cutting	77Hb18Be5Ac	174	–	4.40	65Hb32Be3Ac	–	2 467	788
		after cutting	70Hb26Be4Ac	147	15.5	–	53Hb43Be4Ac	35.7	1 587	690
	2008	before cutting	68Hb27Be5Ac	196	–	4.90	57Hb39Be4Ac	–	2 510	978
		after cutting	60Hb35Be5Ac	140	28.6	–	48Be47Hb5Ac	25.5	1 870	892
	2016	without cutting	56Hb38Be6Ac	187	–	5.88	48Be46Hb6Ac	–	2 460	1 169

Hb – hornbeam (*Carpinus caucasica* A. Grossh.); Be – beech (*Fagus orientalis* Lipsky); Mp – maple (*Fraxinus excelsior* Lipsky); O – oak (*Quercus iberica* Stev.); Ac – acer (*Acer platanoides* Lipsky)

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trunks, respectively) and the forest stands were in the phase of intensive growth with a current increment increase of 2.8 $m^3 \cdot ha^{-1}$ and 4.2 $m^3 \cdot ha^{-1}$, respectively. Therefore, the intensity of thinning the stands was taken at the level of 13.6% and 20.1%, respectively, in the second procedure of selective cutting. The selection of the trees was carried out mainly from the hornbeam part of the upper tree layer, while from the beech trees, those were only cut based on the condition of the trees. As a result, the participation percentage of the beech trees in the composition of these forest stands increased by 19.2% and 16.1% in stand volume, respectively. The damage to the forest stands amounted to 6.2% and 6.6%, respectively.

By taking the incomplete regeneration of forest stands in the second procedure of cutting at the P-1 and P-3 into account, a moderate intensity of cutting was accepted – 18.6% and 19.6%, respectively, after which the participation percentage of beech trees in the younger generation increased by 12.5 % and 12.1% in number, respectively. At the end of the complex cutting in these forest stands, 66 and 82 regeneration sites per hectare around the beech seed trees were created the second time.

By the time of the third complex cutting procedure, the P-1 and P-3 plots were fully restored with the current increment of 3.9 $m^3 \cdot ha^{-1}$ and 5.6 $m^3 \cdot ha^{-1}$, respectively. The intensity of the selective cutting applied in this procedure was 18.4% and 24.6%, respectively. As a result of the selective cutting, the participation percentage of the beech trees in the composition of these forest stands increased 20.6% and 13.5% in stand volume, respectively. The damage to the forest stands was 7.2% and 5.4%, respectively.

In the third thinning procedure in the P-1 and P-3 forest stands, 27.5% and 15.5% sampling intensity was applied to the trees, respectively. Due to the sampling, mainly of the hornbeam, the participation percentage of the beech trees in the composition of the undergrowth of these forest stands increased by 23.8% and 7.0%, respectively.

In total, for the three complex cutting procedures with P-1, the following were harvested: by selective cutting – hornbeam 70.0 m^3; beech 7.9 m^3; by the thinning – 2 646 per hectare for the hornbeam, and 149 per hectare for the beech. At P-3, these indicators were: 120.5 m^3 and 18.8 m^3; 796 and 140 per hectare, respectively (Figure 1).

During the last survey in forest stands P-1 and P-3, conducted 8 years after, it was found that the stand volume is actively accumulating. The current increment increase for the specified period reached 5.13 $m^3 \cdot ha^{-1}$ and 6.13 $m^3 \cdot ha^{-1}$, respectively. The beech stand volume in the composition of these forest stands has increased by more than 3.0 and 2.2 times, respectively, in comparison with the stand volume in the initial forest stands, whereas the hornbeam participation percentage decreased by 31.6% and 53.2% of the stand volume, respectively.

During the first procedure, selective cutting with an intensity of 14.6% and 20.0% was applied in plots P-2 and P-4, respectively. The main attention was paid to the hornbeam, which led to an increase in the participation percentage of the beech trees in the composition of the stand by 3% and 4% on the stand volume, respectively. The damage to the stand was 10.7% and 11.0%, respectively. In the young generation of these forest stands, thinning was carried out with an intensity of 26.0% and 26.5%, respectively, after which the participation percentage of the beech trees in the undergrowth increased to 13.6% and 14.8%, respectively. In these forest stands, at the end of the first complex cut-

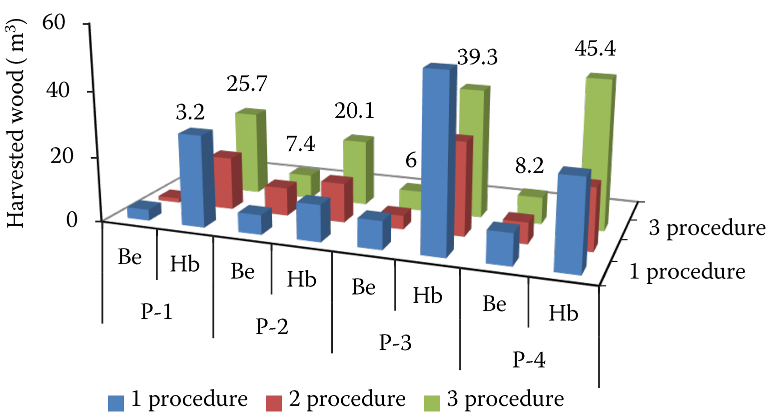

Figure 1. Indicators of the volumes of the harvested wood in the three selective cutting procedures on 4 plot
Be – beech; Hb – hornbeam

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ting procedure, 104 and 86 regeneration sites per hectare were created around the beech seed trees.

By the second complex cutting procedure at P-2 and P-4, an incomplete regeneration of the forest stands was observed (from up to the cutting, 97.7% and 91.6% of the stand volume and 94.1% and 80% of the number of trunks, respectively). The current increment increase for the specified period was 3.2 $m^3 \cdot ha^{-1}$ and 4.2 $m^3 \cdot ha^{-1}$ respectively. Due to the relatively high growth of these forest stands in the second selective cutting procedure, the thinning intensity was taken at 17.3% and 15.5%, respectively. The cutting was mainly carried out at the expense of the hornbeam, as a result of its participation in the composition of forest stands decreased, and the participation of the beech increased proportionally.

During the second thinning procedure, it was found out that, within the 5 years, the total amount of undergrowth at P-2 was incompletely restored (from the up to the cutting 91.2%), and at P-4 was completely restored, while the amount of undergrowth of the beech increased by 18.8% and 24.7%, respectively. By taking the dynamics of the recovery processes of the younger generation into account, the intensity of the thinning occurred at 15.6% and 35.7%, respectively. At the end of the second complex cutting procedure, 76 and 68 regeneration sites per hectare were created around the seed trees of beech of these forest stands.

By the third complex cutting procedure, the P-2 and P-4 forest stands were fully regenerated. The intensity of the sampling trees in the third selective cutting procedure was taken at the level of 20.4% and 28.6%, respectively. As a result of the third selective cutting procedure, the percentage of beech increased about 30% in the stand volume, with the participation of 44% and 35% in the composition of these forest stands, respectively. The damage to the stands amounted to 8.6% and 10.4%, respectively. During the cutting, 32.9% and 25.5% of the thinning intensity of the younger generation were used, due to which the participation percentage of the beech trees in the undergrowth increased by 28.5% and 23.1%, respectively.

In total, for three complex cutting procedures with P-2, following amounts were harvested: by selective cutting – hornbeam 43.3 m^3; beech 22.0 m^3; by the thinning – 3 036 per hectare, including the beech – 409 per hectare. At P-4, these indicators were: 91.6 and 24.3 m^3; 2 140 and 283 per hectare, respectively (Figure 1).

In the last accounting of the P-2 and P-4 forest stands, it was found that the stand volume of the beech trees increased by more than 1.7 and 2.2 times in comparison with their initial compositions. However, the participation percentage of the hornbeam as a second important woody species in stand volume of these forest stands decreased by 32.2% and 29.1%, respectively. The current increment increase was 5.50 and 5.88 $m^3 \cdot ha^{-1}$, respectively.

In this research, the work presented the dependences of the number of beech undergrowth (*N*) and the total stand volume (*M*) of the forest stands spread out on the northern and southern slopes from the share of the beech trees (*Sh*) in the parent stand (Figure 2) in a graphical form, while at the same time, the mathematical models of these dependencies were derived:

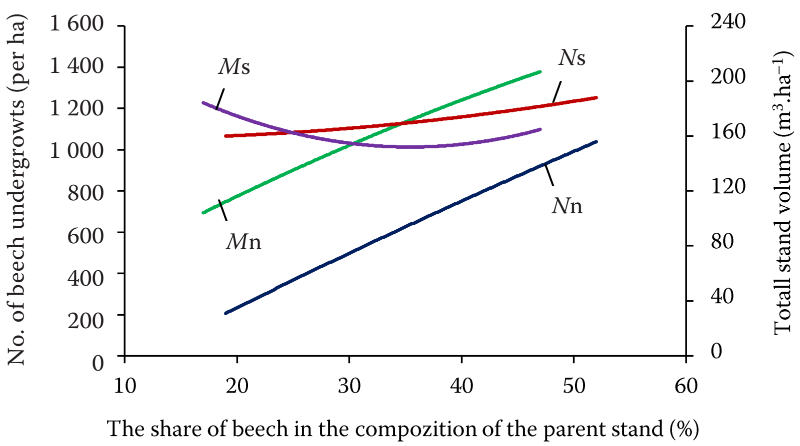

Figure 2. Dependence of the amount of beech undergrowth (N_n, N_s) and the entire total stand volume (M_n, M_s) from the share of the beech trees in the composition of the parent stand

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(*i*) for the northern slopes:

$N_n = -5.93Sh^2 + 294.42Sh - 332.24$;

$R^2 = 0.909$; $r = 0.953 \pm 0.34$;

$M_n = 1.52Sh^2 - 2.31Sh + 158.82$;

$R^2 = 0.192$; $r = 0.433 \pm 0.15$,

(*ii*) for the southern slopes:

$N_s = -13.83Sh^2 + 316.48Sh + 195.86$;

$R^2 = 0.965$; $r = 0.980 \pm 0.35$;

$M_s = 9.47Sh^2 - 67.08Sh + 270.78$;

$R^2 = 0.212$; $r = -0.300 \pm 0.11$.

In the forest stands distributed on both mountain exposures, there was a strong correlation between the N and the Sh, and a weak correlation between the M and the Sh.

DISCUSSION

In order to reform all the forest stands and to only grow the beech part of the secondary hornbeam stands of this forestry system, a complex cutting was carried out with an intensity: on the northern slopes, from 13.6% to 31.0% in the stand volume, and on the southern slopes, from 14.6% to 28.6%. The current increment growth after three selective cutting procedures, including the last registration carried out in 2016, increased on the northern slopes from 2.80 to 6.13 $m^3 \cdot ha^{-1}$, from 3.20 $m^3 \cdot ha^{-1}$ to 5.88 $m^3 \cdot ha^{-1}$ on the southern slopes. The participation percentage of the beech trees in the forest stands of the northern slopes reached 49% and 52% in the stand volume (P-1 and P-3, respectively), and to 38% and 47% on the southern slopes (P-2 and P-4, respectively). The damage to the stands during these cutting periods was comprised of 11%, which is within the considered tolerance. In the initial forest stands, as part of the undergrowth, the beech was represented by: 8% and 19% in number io the northern slopes (221 and 280 per hectare in P-1 and P-3, respectively); and 22% and 27% (632 and 924 per hectare in P-2 and P-4, respectively) on the southern slopes. This is several times less than the required amount of beech undergrowth for their natural regeneration.

For the purpose of increasing the number and ensuring an even distribution over the area of the young part of the beech and the entire upper tree layer, the second complex cutting procedure was conducted five years later in 1998, and third after 10 years in 2008.

The indicators of periodicity and intensity of the thinning applied by us in the beech forest stands of the Greater Caucasus corresponded to the data obtained from studies in the secondary beech forests of Italy, where a periodic thinning with moderate and heavy intensity was used (Chianucci et al. 2016). These types of thinning intensities are also applied in beech forests of Central Europe, where positive results were obtained on the regeneration of stands by the free-crown thinning method (Stefancik et al. 2018). Here, the cutting of trees was carried out by taking the "openness of the canopy" within 15–25 m^2 into account, allowing the growth and development of the young generation of beech trees. This conclusion was drawn by both Iranian (Tabari 2006) and Azerbaijani (Yakhyayev 2016) authors exploring the regeneration process of beech stands in the east in different size areas. In addition, after the first two thinning procedures, as a contribution to the renewal process in places poorly distributed by beech trees, the "regeneration sites" were created (Yakhyayev et al. 2018).

The results obtained at the last registration showed that the beech trees in the composition of the undergrowth participated 34% and 52% in the forest stands of the northern slopes of P-1 and P-3, respectively. Here, in the structure of the large undergrowth and the thin log amount, the beech has significantly increased, which is the main element in the formation (rearing) of the second tier and the addition (updating – reforming) of the upper canopy.

These recommendations are consistent with the conclusions of Sukachev et al. (1957) who once noted that in order to regenerate the forest stands, there should be a sufficient number of evenly distributed parent trees in the stands. On the other hand, in the manuscript of Yakhyaev et al. (2015), it was found that in order to regenerate beech stands in the undergrowth, the participation percentage of the beech should be at least 40–50% in number.

The participation percentage of the beech in the undergrowth of the forest stands of the southern P-2 and P-4 slopes in the last registration reached 39% and 48%, respectively. Here, the process of accumulation of the undergrowth and the thin log amount, the beech proceeds unequally. In the forest stands of P-2, the accumulation of the undergrowth of the subsequent renewal is slow, and in the large undergrowth and thin log amount of P-4, the beech trees have significantly increased due to its preliminary regeneration.

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As can be seen in secondary hornbeam stands common on the southern exposures of the mountain slopes, the native regeneration, i.e., the rate of increasing the beech undergrowth in numbers is 2–4 times lower than the regeneration of this species in the slopes of the northern exposures. This is mainly due to the favourable conditions for the abundant regeneration of the hornbeam in the southern exposures, a decrease in the protection of the upper layers of the soil from the draining and the small undergrowth of beech - by thinning the upper canopy from the sun's radiation in these conditions. On the other hand, the inter-specific competition of the hornbeam with the beech is strongly evident in the southern slopes, affecting the numbers of the younger generation of beech trees and the stand volume of the entire forest stand with the superiority in the hornbeam composition (Mishnev 1986).

It can be said that, in the secondary hornbeam stands with the help of complex cutting, it is possible to regenerate native beech forest stands. However, the obtained data indicate that in order to ensure the sustainability and irreversibility of the process of regenerating the beech parts, it is necessary to increase complex cutting procedure. On the other hand, the success of the regeneration process of beech stands by using complex cuttings was noted (Yakhyaev 2014; Gryazkin et al. 2016) in the study of the secondary birch stands of Russia and the hornbeam stands of the Greater Caucasus, respectively. Here, the main parameters of the complex cutting, and regeneration process correspond to the obtained parameters.

CONCLUSION

It has been established that with the use of complex cuttings in the secondary hornbeam stands of the Greater Caucasus, it is possible to regenerate native beech stands, and, at the same time, it is necessary to carry out: (a) 3-4 procedures on the northern exposures of the slopes; (b) 4–5 cutting procedures on the southern exposures.

It has been established that in order to successfully regenerate the native beech stands of the Greater Caucasus as part of the secondary hornbeam stands, the participation percentage of beech must be increased: (a) on the northern exposures – as a part of the parent stand, by up to 60–70% – in the stand volume – as a part of undergrowth, to 50–60% in number; (b) on the southern exposures by up to 50–60% in the stand volume and by up to 40–50% in number, respectively.

The established mathematical models of the regeneration process of native beech stands reflect the dependence of the amount of the beech undergrowth and the total stand volume from the share of the beech participation in the secondary hornbeam stands.

Recommendations on the regeneration of native beech stands in secondary hornbeam stands of the Greater Caucasus were developed and presented to the forestry authorities of the region for their practical application.

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