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TITLE: Research on the installation, growth and development of natural regeneration in mixed species riparian forests

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PhD Thesis Abstract

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1. Introduction

Due to its multiple environmental, economic and social valences, the pedunculate oak is one of the most valuable forest species in Europe. In Romania, it is a main species in the composition of mixed species riparian stands, being present especially in the lowlands, including the floodplain areas. It can form both pure stands, but also mixtures with other oak species or with other deciduous species (linden, hornbeam, sycamore, elm, ash) forming mixed species stands in the low plains or in the riparian floodplain area (Negulescu and Săvulescu 1957). The successful management of these forests, in terms of maintaining the oaks and obtaining high quality timber, requires special attention in terms of controlling mixtures and regulating the density of stands, and at the time of regeneration, ensuring optimal conditions for abundant natural regeneration well distributed over the surface (Savill 2019, Roloff et al. 2000).

As such, the natural regeneration (from seed) of pedunculate oak, is one of the main objectives of current silviculture not only to reduce costs but, above all, to promote local provenances, but also regional genetic diversity, as an effective method for increased adaptability to climate change. However, this goal remains a challenge at present, considering not only the problems raised by the reduced frequency of seed mast events in the pedunculate oak, but also the challenges the species currently faces due to climate change (which creates more favorable conditions for the development of certain biotic disturbing factors and thus lead to the exacerbation of their negative effects), as well as due to the accidental introduction of exotic species of insects and pathogens (fungi, viruses, bacteria). In addition, the reduction in the frequency of flooding in the floodplains, as well as the lowering of the water table, both present in the case of riparian stands, are considered as potential causes for the decline of the pedunculate oak ("acute oak decline") in the floodplain areas (Stojanović et al . 2015).

2. The purpose and objectives of the research

Considering the above, both the regeneration of oak stands and mixed species riparian stands, and the tending of natural regenerations obtained in these forests, are two sides of modern silviculture that require special attention and thorough research. As such, the doctoral thesis aimed to highlight the defining characteristics of the natural regeneration of mixed species riparian stands group shelterwood cuttings, in the context of applying cleaning respacing in different ways. In order to fulfill the purpose of the research, the following specific objectives were defined:

1. Present the current state of knowledge regarding the establishment, growth and development of natural seedlings in mixed species riparian stands;

2. Analysis of the natural regeneration potential (size, dimensions, composition) in mixed species riparian stands after the application of group shelterwood cuttings and related tending operations (in the first 5 years);
3. Highlight the main characteristics of the dynamics of growth and development of natural seedlings in mixed species riparian stands in the context of applying cleaning respacing in different ways.

3. Study site. Materials and Methods.

3.1. Study site

The research activity was carried out within the Bucharest Forest District, subcompartment 54C, Bartoneasa forest, from Production Unit V Jilava. From a geographical point of view, the research site is located in the Romanian Plain, south of Bucharest City (44.279974 lat. N; 26.114963 long. E) (Figure 1 – red dot).

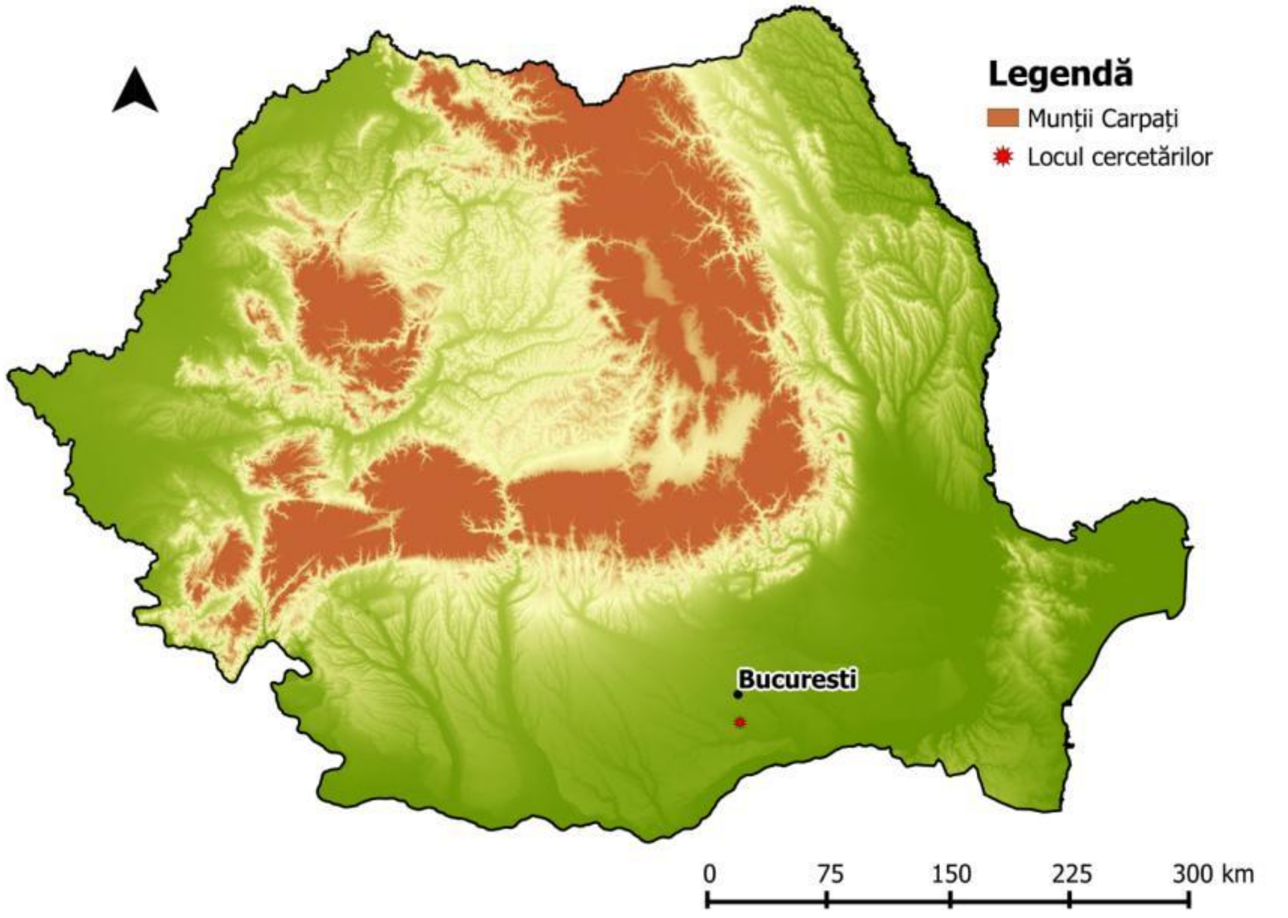

Figure 1 The place of research

Regarding the management of the stand where the research was carried out, in the past decade (2010-2020), three group shelterwood cutting were carried out, as follows:

- Intervention I (Fall 2012). Gap opening cut. A total of 15 regeneration gaps with a diameter of approx. 1.0H-1.5H were opened (Figure 2b). A few oaks were left as seed trees in the gaps, the canopy cover being reduced to 0.2-0.4. In the rest of the stand there was no cutting;
- Intervention II (2014 spring). The previously opened regeneration gaps were widened, other regeneration gaps were opened and the entire surface was covered with sanitation cuttings. Where it was the case, the extraction of unusable regeneration was also carried out;
- The 3rd intervention (2016 spring). The remaining seed trees were completely extracted and the stand canopy cover between the gaps was greatly reduced to approx. 0.2-0.3.

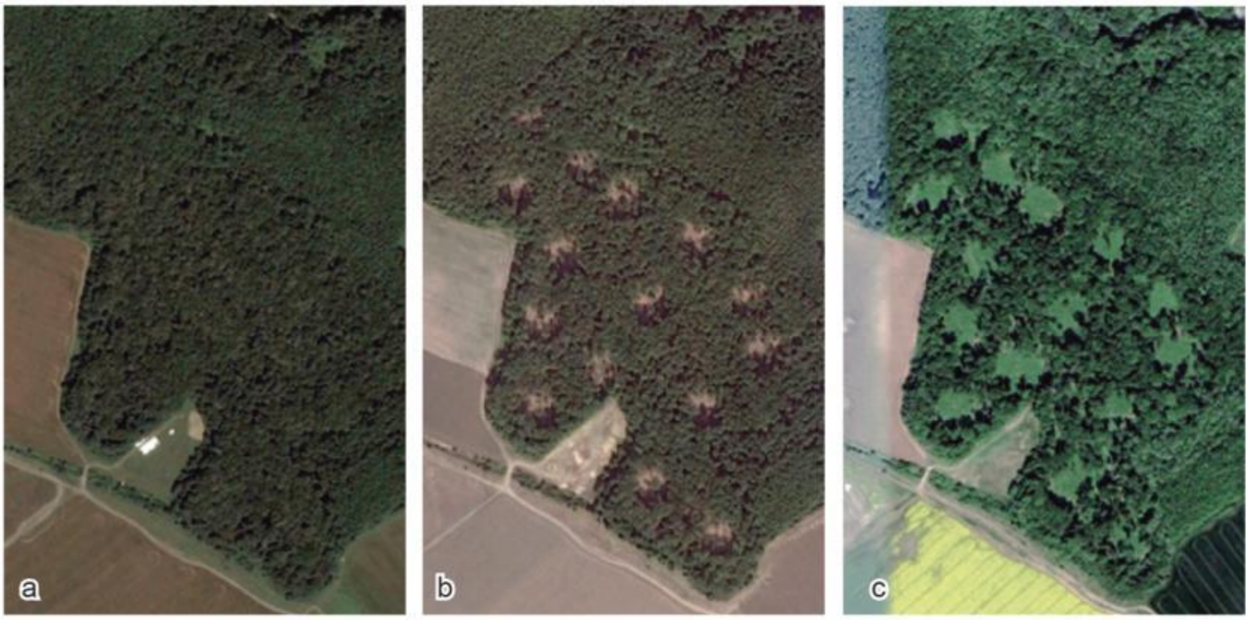

Figure 2 The stand studied (a) before the opening of the gaps, (b) after their opening in 2012 and (c) after their widening and the extraction of the seed trees in 2016 (source: Google Earth)

In order to ensure the success of the installed regeneration, tending operations (weeding, extraction of unusable seedlings) were carried out annually in the open gaps. In the places where the regeneration has reached the canopy closure, cleaning-respacing works were applied.

3.2. Materials and methods.

The measurements were initiated in the fall of 2017. From the total of 15 regeneration gaps opened in 2012, eight of them were randomly chosen (gaps no. 1, 2, 3, 6, 7, 8, 9 and 10). In them, two perpendicular transects were delineated, on the SN and EW directions. Along each transect, using a tape, sample plots of 9 m^2 (square shape, 3 x 3 m) were placed every 10 m. Six sample plots were thus placed on each transect: two on the edges (one at each end), two in intermediate position (halfway between the center and the edge), and two in the central area of the gap (Figure 3).

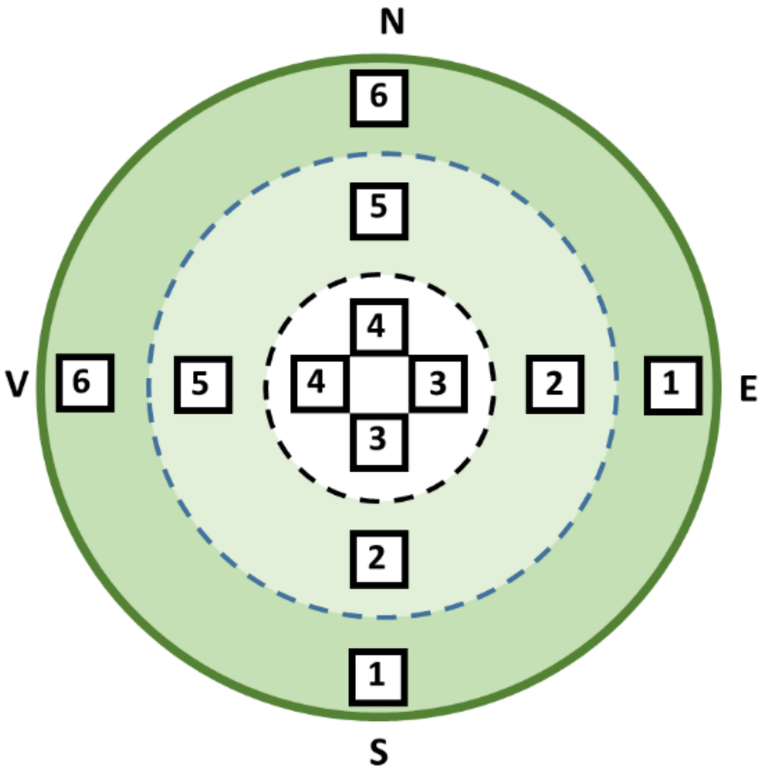

Figure 3 Spatial arrangement of transects and sample plots in the regeneration gaps

Further, in each of these sample plots, all seedlings were inventoried, recording the following information for each one: species, total height, annual growth in height and the diameter at the root collar. Measurements were carried out annually, after the growing season, starting in the fall of 2017 and completed in the fall of 2019-early 2020.

In six of the regeneration gaps chosen for the study (gaps no. 1, 6, 7, 8, 9 and 10) tending operations (cleaning-respacing) were carried out to promote the installed natural vegetation. In order to assess the effect of these works, in all research plots in these gaps, depending on the availability in the field, between three and seven oak seedlings were chosen (marked with red paint) to be kept (and therefore to be favored further by the tending works). Where there were not enough pedunculate oak seedlings or none at all, seedlings of other species were chosen, so as to ensure a density of seedlings (which will be favored by further maintenance work) between 2,500 and 7,000 seedlings per hectare.

Subsequent tending works aimed at promoting selected seedlings. The remaining two gaps (gaps no. 2 and 3) were considered as control areas. As such, in order to be able to follow the natural evolution of the installed seedlings, no tending work was done and no specific seedlings were chosen to be maintained. During the 2018 and 2019 growing seasons, cleaning-respacing works were carried out in the six chosen regeneration gaps, in three different ways:

- in gaps no. 7 and 9, cleaning-respacing works were made by cutting the competing vegetation from ground surface (hereinafter called "cutting from the ground surface");

- in gaps no. 6 and 8 cleaning-respacing works were carried out, by breaking the competing vegetation at 1/2 of the height of the oaks chosen to be maintained in the future (hereinafter called "breaking from 1/2");
- in gaps no. 1 and 10 cleaning-respacing works were carried out, by breaking the competing vegetation at 1/3 of the height of the oaks chosen to be maintained in the future (hereinafter called "breaking from 1/3").

For each individual gap and for each measurement period, the following data/information were recorded:

- the number of seedlings inventoried at transect and sample plot level, by species; based on these data, by extrapolation, densities were obtained at gap and at hectare level and the composition was established (the symbols used were taken from the species codes used in forest management planning - e.g. pedunculate oak - ST, common ash - FR, the silver linden - TE, the hornbeam - CA and various hardwoods - DT, among which the hedge maple - JU and the field elm - ULC);
- the dimensions of the seedlings (height, diameter; based on the collected data, the minimum, maximum, average values were determined) from each sample plot, for each individual species;
- the type of tending work performed and the year in which the measurements were performed;
- under "observations", using the same coding system, the species of trees that do not influence the composition of the future stand (cherry plum - CD, white mulberry - DD, Tatarian maple - AR and Paradise tree - CS) were also entered, as well as the species of shrubs (hawthorn - L, warted spindle tree - P, black elder - R and dogwood - T);
- also under "observations", the number of seedlings of other hardwoods was detailed for each species (for example, hedge maple JU and field elm ULC, respectively);

In addition to the growth measurements made on the seedlings from the sample plots, in order to characterize the light regime in which the seedlings develop in various portions of the regeneration gaps, in the summer of 2019 hemispherical photographs were recorded (with the WinScanopy system – Regent Instruments , Canada) in three gaps, with different intervention types ("cutting from the ground surface", "breaking from 1/2" and "breaking from 1/3"). Due to time constraints, one gap was chosen from each type of tending work (gaps 1, 8 and 9) and a photo or two was/were recorded, as explained below, for each sample plot on the two transects placed in the gap. Photographs were taken in each sample plot, with the camera positioned and leveled at the top of the tallest pedunculate oak seedling in the sample plot. If in its immediate vicinity there was a taller seedling of another species (casting shadow on the camera and affecting the measurement of the light regime available for the sample plot), a second photograph was taken at its tip (to capture the influence of the mature trees from the edge of the gap). The photos were taken under complete overcast conditions, with the solar disk invisible (mandatory conditions to avoid errors in determining the light regime – according to the WinScanopy system instruction manual).

Next, the collected hemispherical photographs were analyzed with the dedicated program (WinScanopy Regent Instruments, Canada) to determine two variables: the "Canopy openness" and the " Percentage of Above Canopy Light" (PACL - i.e., percentage of photosynthetically active light reaching the ground). After analyzing all photographs, the ".txt" file with the results was opened in Microsoft Excel using the dedicated extension (XLScanopy, Regent Instruments, Canada).

3.3. Data analysis

3.3.1. Regeneration density. Regeneration composition. Seedling size.

Based on the data collected from the field, the density per hectare was determined at the sample plot, transect and gap. Density at sampling plot and gap level was calculated by summing the values from all sample plots (6 squares x 9 m2/square in the case of transects and respectively 12 squares x 9 m2/square in the case of gaps) the results being later extrapolated per hectare. For composition, the total number of seedlings of a species from all sample plots related to a gap was first calculated (as the sum of plot-level values). The number was extrapolated per hectare (resulting in the presence of the species per hectare). Later, this result was divided by the total number of seedlings (of all species) per hectare (calculated as described above), resulting in the percentage of participation of each species in the composition.

Also, in order to evaluate the effect of the application of groups shelterwood and the related tending works (after the first 5 years after installation), the average dimensions of the seedlings (diameter at the root collar and height) were calculated at the level of the sample plot, both for all species together as well as separately for pedunculate oak seedlings only. In addition, in order to detect certain spatial trends within the regeneration gaps, for the pedunculate oak, the average dimensions were calculated for each position within the regeneration gaps (on the two transects – see Figure 3).

3.3.2. Evolution and growth of regeneration

In order to analyze the evolution of the natural regeneration density, the difference was made between the values per hectare (obtained according to those presented in 3.3.1.) for the years 2017 and 2019, respectively, using the following calculation equation:

$$\text{Reduction } (\%) = \frac{(\text{seedlings.no}/\text{ha } 2017) - (\text{seedlings.no}/\text{ha } 2019)}{(\text{seedlings.no}/\text{ha } 2017)} \times 100 \qquad \text{[equation 1]}$$

To analyze the regeneration growth, the difference between the average values at gap level (obtained as the arithmetic mean of all the values recorded in the sample plots from ap articular gap) for the years 2017 and 2019 was calculated using the following calculation equation:

$$\text{Difference} = (\text{avg\_val\_2019}) - (\text{avg\_val\_2017})$$

The results were also expressed as a percentage, using the following calculation equation:

$$\text{Difference }(\%) = \frac{(\text{avg\_val\_2019})-(\text{avg\_val\_2017})}{(\text{avg\_val\_2017})} \times 100$$ [equation 2]

3.3.3. Effect of location within gaps and of type of tending works

For the analysis, similar to previous research (Modrow et al. 2020), out of all seedlings from a sample plot (of 9 m^2) the five tallest pedunculate oak seedlings were chosen. This number ensures a species density of 5,555 seedlings per ha, a sufficient number to ensure the success of the species in the structure of the future stand, these trees being further favored through the tending operations. If the number of pedunculate oak seedlings was less than five, all existing individuals were chosen.

For the selected seedlings, based on the measured dimensions (height in cm and diameter at root collar in mm), the total above-ground biomass was determined with the help of an allometric formula (equation 1), obtained with the help of the data set from Blujdea et al. (2012), made available by Dutcă I. (pers. comm., March 2024).

$$BST = e^{-2,793} \times D_c^{1,7772} \times H^{0,6802} \times 1,02737$$ [equation 3]

where: BST – total above-ground biomass (including foliage), in kg; Dc – root collar diameter, in cm, H - total height, in m; 1.02737 – correction factor calculated as $e^{(0.2324\text{^}2/2)}$

Next, for each variable (height, root collar diameter, total above-ground biomass), based on the average values (calculated as an arithmetic mean), a comparative analysis (t test) was carried out between the different areas of the gap (central, intermediate and edge; edge areas in the south-west compared to those in the north-east) and on each type of tending work (control – no interventions; "cutting from the ground surface"; "breaking from 1/2"; "breaking from 1/3"). The analyses were carried out using measurements made in two years: 2017 (5 years after the start of the regeneration cuts, during which the tending works on the installed regeneration were carried out uniformly - by the same method - in all the gaps) and in 2019 (after 2 growing seasons in which differentiated works were applied). Using the Microsoft Excel program, suggestive box-plot graphs were also created for each individual case.

4. Results and discussions

4.1. The potential for natural regeneration in mixed species riparian stands after the application of where group shelterwood regeneration cuttings

[Note: Data from the article " Regenerarea naturală într-un șleau de luncă din Ocolul silvic București", authors Ghinescu, M.-N., Nicolescu, V.-N., Stăncioiu, P.-T., published in 2022 in Bucovina Forestiera journal 22(1): 7-20].

4.1.1. Density of regeneration

The number of seedlings per hectare in 2017, extrapolated from the inventory of seedlings from the sample plots, was over 100,000 (except for gaps 9 and 10), which demonstrates a very high regeneration capacity. Even in the two gaps with lower densities, the number of seedlings per hectare is clearly higher than what is considered in the technical norms in force as suitable for the success of natural regenerations (10,000-15,000 seedlings per hectare for regeneration between 1 and 4 years; 8,000 seedlings at hectare when achieving the canopy closure - Anonymous 2022b). A synthesis for each sample plot and gap level is shown in Table 1.

Table 1 The number of seedlings in the studied plots (no. seedlings/ha)

Gap no.	Transect	Sample plot SP1	SP2	SP3	SP4	SP5	SP6	Transect average
1	S-N	121.111	97.778	55.556	106.667	93.333	72.222	91.111
	E-W	77.778	81.111	185.556	135.556	164.444	84.444	121.482
	Gap Total		**106.296**					
2	S-N	15.556	175.556	91.111	85.556	182.222	306.667	142.778
	E-W	74.444	52.222	151.111	105.556	63.333	70.000	86.111
	Gap Total		**114.444**					
3	S-N	107.778	231.111	106.667	76.667	75.556	136.667	122.407
	E-W	147.778	134.444	86.667	147.778	160.000	101.111	129.629
	Gap Total		**126.019**					
6	S-N	63.333	83.333	71.111	95.556	101.111	83.333	82.963
	E-W	102.222	188.889	87.778	103.333	116.667	147.778	124.445
	Gap Total		**103.704**					
7	S-N	166.667	114.444	142.222	166.667	110.000	124.444	137.407
	E-W	92.222	76.667	141.111	148.889	115.556	93.333	111.296
	Gap Total		**124.352**					
8	S-N	127.778	106.667	82.222	194.444	84.444	90.000	114.259
	E-W	97.778	56.667	88.889	40.000	106.667	148.889	89.815
	Gap Total		**102.037**					
9	S-N	43.333	72.222	56.667	110.000	75.556	148.889	84.445
	E-W	84.444	100.000	118.889	47.778	51.111	121.111	87.222
	Gap Total		**85.833**					
10	S-N	42.222	142.222	27.778	12.222	120.000	101.111	74.259
	E-W	16.667	48.889	15.556	50.000	163.333	113.333	67.963
	Gap Total		**71.111**					

As can be observed, the number of seedlings per hectare in the analyzed plots varied widely, from 71,111 in plot 10 to 126,019 in plot 3. At the sample plot level, density values are even more diverse, ranging from 12,222 seedlings/ha (gap no. 10, transect SN, sample plot 4) to 306,667 seedlings/ha (gap no. 2, transect SN, sample plot 6). This fact indicates a very uneven spatial distribution, typical of mixed natural regenerations, installed in successive episodes. The analysis of the number of seedlings along the transects, in the two chosen directions (SN and EW), confirms the spatial variability in density. Regarding the results on density by species, the data for each gap are shown in Table 2.

Table 2 The number of seedlings per hectare per species in the studied plots

Gap no.	Pedunculate oak	Common ash	Linden silver	Hornbeam	Other hardwoods	Total
1	45,278	92	33,611	19,352	7,963	106,296
2	37,778	185	43,981	22,778	9,722	114,444
3	36,111	0	55,926	16,389	17,593	126,019
6	28,704	926	48,426	9,444	16,204	103,704
7	15,278	9,630	63,148	17,130	19,166	124,352
8	13,333	20,926	27,963	10,000	29,815	102,037
9	25,463	2,685	18,148	27,037	12,500	85,833
10	25,278	185	28,241	10,092	7,315	71,111

In the case of oak, the number of seedlings per hectare varies from 15,278 (in gap 7) to 45,278 (in gap 1), confirming the above rule, valid for the species considered together. The relatively low density of ash, a typical floodplain species and the relatively high density of hornbeam and linden (species characteristic of mesic conditions), which, in conjunction with the data describing the soil in the study area, may indicate a transition to a mixed stand from low plains rather than one form the riparian floodplain area.

Discussions

In the present study, after 5 growing seasons from the initiation of regeneration cuttings, at the level of all the plots analyzed, an average number of 104,225 seedlings per hectare was recorded (from a minimum of 71,111 in plot 10 to a maximum of 126,019 in gap 3). Of these, the main species (pedunculate oak) and secondary species (ash, linden and hornbeam) add up, on average, to 87,941 seedlings per hectare (from a minimum of 62,232 in gap 8 to a maximum of 108,426 in gap 3). Compared to the provisions of the regulations in force regarding the success of natural regeneration installed after regeneration cuts, the situation is very good. In the present case, regarding the target species (pedunculate oak), despite the fact that the number of seedlings per hectare varied between quite wide limits in the analyzed gaps (15,278–45,278 seedlings) and on the installed transects (with a heterogeneous spatial distribution), its regeneration is far above the prescribed thresholds and ensures high chances for its participation in the composition of the future stand.

The success of the regeneration of the pedunculate oak in the studied stand was also favored by the absence of wild boar in. This is one of the biggest acorn consumers, despite the fact that through its activity it disturbs the soil and, in certain situations, favors the natural regeneration of oaks by mobilizing the soil, preventing an unwanted succession by the forester (Pașcovschi 1967). In none of the years of the research were there any signs attesting to the presence of the wild boar in the area. The same situation was confirmed both by the game managers by the forest ranger in charge of the stand. As such, the successful regeneration of pedunculate oak following light seeding episodes (between seed mast years) is a peculiarity to the general case and may influence the results regarding the success of the species observed in this case.

4.1.2. The composition of regeneration

Data from the installed sample plots show quite different composition between regeneration gaps (Table 3). The composition is also variable along the installed transects. The results confirm, therefore, a very diversified composition, both in terms of the species encountered and in terms of their spatial distribution in the analyzed gaps (Table 3).

Table 3 Composition in 2017 based on the number of seedlings in the study plots

Gap no.	Composition in 2017
1	43ST31TE18CA8DT
2	33ST38TE20CA9DT
3	29ST44TE13CA14DT
6	28ST1FR46TE9CA16DT
7	12ST8FR49TE16CA15DT
8	13ST20FR28TE10CA29DT
9	30ST3FR21TE31CA15DT
10	36ST40TE14CA10DT

After five years from the first felling, the regeneration composition is generally dominated by silver linden, followed by pedunculate oak and hornbeam. The proportion of oak varies from 12% (in gap 7) to 43% (in gap 1). A very low proportion of common ash can be noted in certain gaps (6, 7, 9) or even its absence in others (1, 2, 3, 10), the species being well represented in only one case (gap 8).

Discussions

This heterogeneity in the spatial distribution of the seedlings from various species is normal in the regeneration of mixed stands, established naturally and in successive episodes. In the case of pedunculate oak, with large, heavy seeds, the distribution of regeneration is expected to be more uneven (clustered), being determined both by the location of the seed trees and by the amount of seeds produced by each individual. In the other species, however, due to the lighter seeds and the more abundant and frequent seeding (compared to the pedunculate oak), dissemination should be possible over a larger area and, as such, their spatial distribution should be less uneven. However, a heterogeneous distribution was also found in the case of the respective species, which can be explained by the fact that the data used are based on the extrapolation of the results from the sample plots, where tending works have already been carried out. The respective interventions favored the pedunculate oak whenever it was present and thus, by extracting predominantly the other species, their original natural distribution was altered.

The proportion of ash participation is low for a typical riparian mixed species stand; in the case of this species, the target composition seems difficult to achieve. The reduced presence of ash in the installed regeneration can be explained by a combined effect of recent climatic developments (much longer dry periods) and the deepening of the Sabar River bed, reaching 3-4 m below ground level, which prevents the occurrence of periodic floods, regular, characteristic of the floodplain area, again confirming the transition to a mixed species low plain stand. Thus, these changes in site conditions slightly affect the pedunculate oak and favor the establishment of hornbeam and linden (Pașcovschi 1967), but are less favorable for the perpetuation of ash. The high proportion of hornbeam and linden reinforces this finding. As such, the current situation shows a possible succession trend from a typical riparian mixed species stand, with a lot of ash, to a normal mixed species low plain stand, in which the presence of hornbeam, along with linden trees, is normal (Pașcovschi 1967), contradicting the recommended target composition currently mentioned in the forest management plan. Moreover, the characteristics of the soil in the studied stand already show a trend of evolution towards conditions more characteristic of the low plain than the typical riparian floodplain area.

4.1.3. Sizes of seedlings (diameter at root collar and height)

After five growing seasons from the first regeneration cut, the average diameter of the seedlings varies within fairly tight limits, from 9.6 mm in gap 2 to 11.8 mm in gap 7. It is important to note, however, the fact that these average values come from highly variable individual data: for example, the minimum diameter recorded is only 1 mm at root collar in gap 3, while in gap 7 the maximum value of 42.7 mm is recorded. In the case of height, the average values in the gaps are also quite close: between 62 cm and 83 cm, except for gap 8, where it reaches only 56 cm. Similarly, as with diameter, individual values vary widely, from 7 cm in gap 3 to 270 cm in gap 9.

Regarding the target species (pedunculate oak), the average diameter achieved in 2017 varies from 7.1 mm to 9.9 mm, and the average height varies from 61 cm to 93 cm. At gap level, the results obtained in the sample surfaces are highly variable, both in terms of diameter (from 1.1 mm in gap 3 to 26.4 mm in gap 9) and height, which vary between the same limits previously mentioned for the entire set of measured trees.

At gap level, in the case of pedunculate oak, the data regarding the two measured variables do not show a constant trend in the two chosen directions (EW and SN). Cumulative results for the same position in the gap (sample plot) from all gaps, however, provide an overall picture that reveals that there would be such a trend (Figure 4), both height and diameter increasing from E to W and from to N to S.

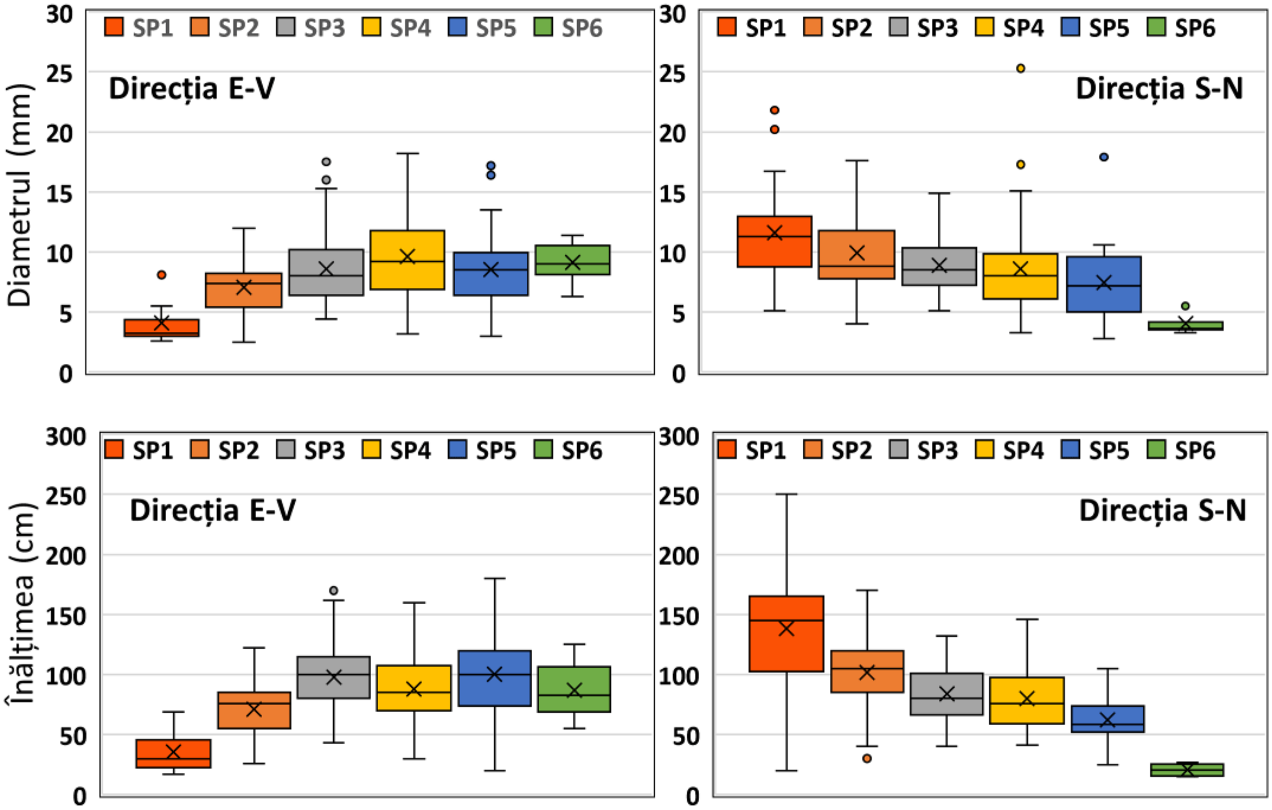

Figure 4 The evolution of the root collar diameter and the height of the pedunculate oak seedlings from the plots analyzed in the two directions of analysis (EW and SN). Data are aggregated from all analyzed gaps, for each gap position/sample plot

Discussions

Significant variation in diameters and heights is a normal feature of natural regenerations installed in successive waves. In addition, this heterogeneity is also explained by the differentiation produced due to the rapid dynamics of young regenerations in conditions of very high density (another characteristic of natural regenerations). The relatively close average values, however, show a trend of uniformity at the stand level either due to site conditions or as an effect of uniformly applied works.

As for the pedunculate oak, the average root collar diameter recorded, which is slightly lower than that of all species considered together (at the stand level), can be explained by the ecology of the species. Thus, during the first years of life, seedlings of the species invest heavily in roots, which sink deep into the soil (Haralamb 1967) and, as such, the resources allocated to growth in diameter are reduced. In addition, is light demanding and in the context of mixing with species with dense crowns, that shade heavily, such as hornbeam and linden, the oak seedlings invest more in height growth. Moreover, the data on the height of the oak seedlings show that they are higher on average (from 60 cm in gap 8 to 91 cm in gap 1 and 93 cm in gap 9) compared to the other species (the average of all seedlings is from 56 cm in gap 8 to 83 cm in gap 1) and therefore support this hypothesis. Of course, the mentioned result is also due to the tending works previously applied to favor the pedunculate oak in the competition with the other species.

Even if at the stand level the site conditions can be relatively uniform, the evolution of the seedlings is strongly influenced by the micro-site conditions. As such, in addition to a wide variation in individual values, found from measurements, a non-uniform (clustered) distribution of these values is also expected to occur. Thus, while the competition from the soil, with the roots of the large trees from the edge of the gaps, should be evenly distributed over the entire circumference of the gaps, that for light is unevenly distributed. This feature is due to the tilting of the sun's rays during the day, which causes the most sheltered portions to be in the eastern and southern edges of an gap, while those in the west and north receive more radiation cumulatively over the course of a day. The non-uniform radiation distribution is supported by the results obtained by summing the data from all gaps at the position (sample plot) level. These results highlight an increasing trend from east to west and from north to south, thus allowing the identification of the so-called "fertile region/margin" of the gaps. This appears to be located in the western and northern areas, where seedlings tend to record both diameters and heights, greater than the rest of the gap surface. In those portions, the seedlings receive more light, even if, with the distance from the center of the gap toward the edges, regardless of the direction chosen, the competition in the soil with the roots of mature trees in the edge of the gap increases. The lack of a uniform evolution (in terms of oak dimensions on the EW and SN directions) at gap level can be explained by the high variability of the available sample, especially the small number and even the absence of oak in certain sample plots, which makes it difficult to detect possible trends.

4.2. Dynamics of growth and development of natural seedlings in meadow sloughs

[Note: Data presented in subchapters 4.2.5 – 4.2.7 come from the article " Evoluția regenerării naturale de stejar pedunculat într-un șleau de luncă din Ocolul silvic București în contextul aplicării degajărilor prin metode diferite " (authors Ghinescu, M.-N ., Stăncioiu, P.-T.), year 2024, Bucovina forestieră 24(2): under publication]

4.2.1. The evolution of the number of seedlings

Along with the growth of natural regeneration, but also in the context of the application of tending works, the number of seedlings per hectare (density) was significantly reduced in just 2 years. Depending on the particular situation of each gap (type of work or lack of work – natural elimination), the results are different. A summary of the evolution of the number of seedlings per hectare between the start of measurements (year I, season 2017-2018) and the last episode of measurements (year III, season 2019-2020) is presented in Table 4.

Table 4 Evolution of the number of seedlings per hectare, depending on the works performed

Work type	Gap no.	No. seedlings/ha 2017	No. seedlings/ha 2019	Decrease (%)
"cutting from the ground surface"	7	124352	31296	74.8
	9	85833	22037	74.3
"breaking from 1/2"	6	103704	80278	22.6
	8	102037	63241	38
"breaking from 1/3"	1	106296	67778	36.2
	10	71111	42593	40.1
Control (no work)	2	114444	55278	51.7
	3	126019	46852	62.8

As can be seen from Table 4, the most pronounced decreases were recorded in the gaps where cleaning-respacing was performed by "cutting from the ground surface" (74.8% in plot 7 and 74.3% in plot 9 respectively) and in the control ones (51.7% in gap 2 and 62.8% respectively in gap 3).

Regarding the evolution of the target species (the pedunculate oak), the data for each gap are presented in Table 5. The decrease in the number of pedunculate oak seedlings is greater in the gaps in which we intervened by cutting from the ground surface, due to their mechanical removal, but also in the control gaps, where the decrease is due to natural elimination, the other species being faster growing.

Table 5 The evolution of the number of pedunculate oak seedlings per hectare in the plots studied, depending on the works carried out

Type of work	Gap no.	No. seedlings/ha 2017	No. seedlings/ha 2019	Decrease (%)
"cutting from the ground surface"	7	15278	5648	63
	9	25463	8982	64.7
"breaking from 1/2"	6	28704	9808	65.8
	8	13333	9352	29.9
"breaking from 1/3"	1	45278	26111	42.3
	10	25278	17315	31.5
Control (no work)	2	37778	13426	64.5
	3	36111	6944	80.8

Regarding the percentage decrease, very high values were recorded both in the case of cleaning-respacing by cutting from the ground surface (63% in plot 7 and respectively 64.7% in plot 9), but also in the case of breaking the stem of competing vegetation at 1/2 of the height oak trees (65.8% in gap 6) and in control gaps (64.5% in gap 2, respectively 80.8% in gap 3).

Discussions

In the rapid development phase in which the seedlings in the regeneration gaps are now, inter- and intraspecific competition is intense. Because of this, but also because of the tending works carried out, the reduction of the number per hectare is normal. It is interesting to note that tending works intermediate in intensity (break from 1/2 or 1/3) led to the smallest decreases, both as percentage and in numbers, seeming to mitigate the effect of natural elimination (due to competition), observed in the control plots . While cutting from the ground surface helped to eliminate many of the seedlings that were the subject of the work, breaking from 1/2 or 1/3 had the opposite effect. This probably reduced the effect of competition for the target seedlings, but without creating a large enough advantage for them to win the fight for existence (eliminating the broken ones). Breaking the stem at a certain height (rather than cutting from the root collar) did not result in the removal of the affected seedlings, nor did it provide a large enough advantage to the pedunculate oaks chosen to be retained (resulting in the removal of the broken ones). In addition, the species mainly affected by the works (linden, hornbeam, dogwood) are resistant to shading and, as such, a small (minus) difference in height compared to oak seedlings, whose crowns do not produce dense shade, may affect them less.

Regarding the target species, in the case of the pedunculate oak, as can be seen from Table 7, in all plots regardless of the type of work, after two growing seasons the number of seedlings per hectare registered significant decreases. As in the case of the total number of seedlings (all species taken together), the effect of "cutting from the ground surface" on oak density appears to be similar to that of removal by natural competition. The pronounced decrease recorded in one of the cases with breakage from 1/2 (gap 6) can be explained by the fact that the works affected in certain situations also pedunculate oak seedlings (e.g. the situation where the trees in direct competition with the oaks chosen for to be preserved and promoted were also pedunculate oaks).

4.2.2. The evolution of species composition

A synthesis at the level of all 12 sample plots installed at gap level is presented in Table 8. The composition changed in the sense of increasing the proportion of pedunculate oak, especially in the case of gaps where the tending works were made by cutting from root collar, a large part of the competitors, both oak and the other species, being eliminated. In the gaps where the tending works were made by breaking from 1/2 and 1/3, the proportion of pedunculate oak remained relatively constant, increasing or decreasing by a few percentages (in gap no. 1 and 6 it decreased, and in gap no. 8 and 10 increased).

Table 6 The evolution of the species composition in the studied gaps, depending on the tending works carried out

Work type	Gap no.	Composition 2017 (% of total no.)	Composition 2019 (% of total no.)
"cutting from the ground surface"	7	12ST8FR49TE16CA15DT	18ST10FR53TE10CA9DT
	9	30ST3FR21TE31CA15DT	41ST2FR26TE23CA8DT
"breaking from 1/2"	6	28ST1FR46TE9CA16DT	24ST1FR49TE11CA15DT
	8	13ST20FR28TE10CA29DT	15ST18FR29TE10CA28DT
"breaking from 1/3"	1	43ST31TE18CA8DT	39ST31TE23CA7DT
	10	36ST40TE14CA10DT	41ST30TE16CA13DT
Control (no work)	2	33ST38TE20CA9DT	24ST45TE17CA14DT
	3	29ST44TE13CA14DT	15ST52TE15CA18DT

Discussions

The composition of young regeneration is constantly changing, the forest at such ages being characterized by rapid dynamics. As such, as expected, over the three seasons of measurements, the proportion of species changed. Regarding the significant decrease in the share of pedunculate oak in the control plots (as can be seen in Table 6), this is most likely due to the fact that it was naturally eliminated by the other, faster-growing species. In the case of the gaps where the tending works were made by breaking from 1/2 and 1/3, maintaining a proportion relatively similar to the original one is due to the fact that the pedunculate oak seedlings that were not chosen to be kept did not disappear by tending works carried out only by breaking the stem and they were not eliminated naturally (an otherwise normal result since the purpose of these works is to stimulate the growth of the seedlings chosen to be preserved and not necessarily to eliminate the others).

4.2.3. The evolution of the average diameter of seedlings

With the growth and development of seedlings, not only the composition changes, but also the dimensions of the seedlings (height and diameter). As such, the effect of the tending works (which provide a considerable advantage by reducing competition and providing resources) should be visible after three growing seasons. A comparative analysis on the evolution of the seedling diameter is presented in Table 7. The data in the table represents a synthesis at the level of all 12 sample plots installed at gap level.

Table 7 The evolution of the diameter in the studied gaps, depending on the tending works performed

Work type	Gap number	Diameter 2017 (mm)			Diameter 2019 (mm)			D.avg 2019 – D.avg 2017	
		med.	min.	max.	med.	min.	max.	(mm)	(%)
"cutting from the ground"	7	11.8	2.4	42.7	9.5	1.1	40.3	-2.3	-20
	9	11.4	1,2	38.9	11.0	2.5	51.7	-0.4	-4
"breaking from 1/2"	6	9.7	1.8	39.6	12.8	2,3	39.5	3.1	32
	8	9.9	2.6	30.4	12.2	1.4	39.3	2,3	24
"breaking from 1/3"	1	10.6	2.5	31.3	16.5	1.6	45.1	5.9	56
	10	10.6	1.5	33.3	15.1	4.0	45.7	4.5	43
Control (no work)	2	9.6	2.0	40.6	14.5	3.1	48.8	4.9	51
	3	10.0	1.0	30.8	14.4	0.5	45.8	4.4	44

Regarding the evolution of the target species (pedunculate oak), the data for each gap are shown in Table 8. The diameter increased significantly in the gaps where tending works were carried out by cutting from the ground surface and breaking from 1/3.

Table 8 The evolution of the diameter in pedunculate oak, depending on the tending works performed

Work type	Gap number	Diameter 2017 (mm)			Diameter 2019 (mm)			D.avg 2019 – D.avg 2017	
		med.	min.	max.	med.	min.	max.	(mm)	(%)
"cutting from the ground surface"	7	8.5	3,4	19.3	15.7	2,3	35.6	7.2	85
	9	9.9	2.2	26.4	15.9	2.9	51.7	6	61
"breaking from 1/2"	6	7.1	1.8	14.1	11.0	3,4	29.6	3.9	55
	8	7.4	3.1	16.0	11.3	1.8	32.6	3.9	53
"breaking from 1/3"	1	8.8	2.5	25.3	15.2	2.2	45.1	6.4	73
	10	8.3	1.9	23.5	14.4	4.5	45.7	6.1	74
Control (no work)	2	8.4	2.0	21.0	11.5	3.6	26.5	3.1	37
	3	7.7	1.1	18.3	12.9	3.3	28.4	5.2	68

Discussions

Analyzing the data related to the diameters, centralized in Table 7, an important increase of them can be found, especially in the case of control gaps and those in which tending works were performed by breaking from 1/3. This is most likely due to the differentiation arising as a result of inter- and intraspecific competition, which resulted in large diameters of some seedlings which then influenced the average value. In plots with cutting from the ground surface and breaking from 1/2 was performed, the increase in mean diameter appears to be less when considering all seedlings. Among them, most likely those cut from the root collar were seriously affected in terms of diameter (the resulting sprouts recorded very small diameters or the diameter at the cut did not increase, the tree investing in height) and therefore the average value is also affected. And in the case of the others, broken from 1/2, the investment was mostly in height (to reach the light) and thus the diameter suffered more.

The situation is completely changed when we analyze only the growth for the monitored species, the pedunculate oak (Table 8), without taking into account the diameters of the other seedlings existing in the sample plots. As expected, the average diameter of the pedunculate oak increased significantly in the plots where tending works work were carried out by cutting from the ground surface (where the competition was significantly reduced), while in the areas where the competition remained intense (control plots) recorded the lowest values. It is interesting to note that in the gaps where cleaning-respacing was made by breaking from 1/2 (although the competition with pedunculate oak should be less compared to the situation where the breaking was made at 1/3 and maybe even in the control plots – without works favoring the pedunculate oak) smaller increases were recorded. Here, however, right from the start, the oak seedlings were considerably smaller than in the other plots (including those in the plots chosen as a control).

4.2.4. The evolution of the average height of seedlings

Similarly, as in the case of the diameter, with the growth and development of the seedlings, the height of the seedlings also changes. A comparative analysis on the evolution of seedling height is presented in Table 9. The data in the table represents a synthesis at the level of all 12 test surfaces installed at gap level.

Table 9 The evolution of the height of all seedlings according to the works carried out

Work type	Gap number	Height 2017 (cm)			Height 2019 (cm)			H.avg 2019 – H.avg 2017	
		med.	min.	max.	med.	min.	max.	(cm)	(%)
"cutting from the ground"	7	66	10	180	71	10	390	5	8
	9	73	10	270	90	14	420	17	2. 3
"breaking from 1/2"	6	62	10	200	73	15	363	11	18
	8	56	10	162	68	15	262	12	21
"breaking from 1/3"	1	83	11	250	140	19	420	57	69
	10	74	13	230	129	25	540	55	74
Control (no work)	2	72	10	230	113	10	400	41	57
	3	64	7	240	162	20	410	98	153

Regarding the evolution of the target species (pedunculate oak), the data for each gap are shown in Table 10. The average height increased significantly in the gaps where cleaning-respacing work was carried out by cutting from the ground surface and breaking from 1/3, but also in the control gaps, due to the competition.

Table 10 The evolution of the height of pedunculate oak according to the tending works performed

Work type	Gap number	Height 2017 (cm)			Height 2019 (cm)			H.avg 2019 – H.avg 2017	
		med.	min.	max.	med.	min.	max.	(cm)	(%)
"cutting from the ground "	7	79	2. 3	180	159	22	390	80	101
	9	93	21	270	140	25	420	47	51
"breaking from 1/2"	6	70	15	130	95	20	252	25	36
	8	60	20	118	95	19	262	35	58
"breaking from 1/3"	1	91	15	250	163	35	415	72	79
	10	88	21	230	149	26	540	61	69
Control (no work)	2	76	18	189	118	15	320	42	55
	3	78	7	240	152	30	371	74	95

Discussions

From Table 9, it can be seen that the average height of the seedlings increased the most in the plots in which tending works were carried out by breaking from 1/3, but also in the control plots, a phenomenon that is due to inter- and intraspecific competition for access to light. In the other gaps (cutting from the ground surface and breaking from 1/3), the values were lower. This situation is due to the tending works carried out which, on the one hand, reduce the competition (and therefore the pressure to increase in height) for the chosen seedlings and on the other hand produce trees with very reduced heights due to the cutting from the ground surface or breaking from 1/2 (as such, the average is seriously affected).

Also if we analyze only the pedunculate oak (Table 10), the most intense increases were recorded in the gaps where cleaning-respacing was carried out by breaking from 1/3, as well as in the control gaps, where the oaks, due to the competition from the side, they were forced to grow in height. An exception occurs, however, in one of the gaps with cutting from the ground surface (gap 7), where the seedlings showed very vigorous growth in height. It is very likely that these are seedlings that were already well developed at the time of the differentiated application of the works and thus they accelerated the growth even more. In the gaps where cleaning-respacing by breaking from 1/2 were performed, an intermediate situation between those previously mentioned probably occurred: the competition was reduced, but not enough to result in a very active increase in height; on the other hand, the shading from the side (which was reduced) did not force the height increase too much either.

4.2.5. The effect of the fertile edge of the gaps

Regarding the fertile edge of the gaps, for the S-W edge the values from the sample plots no. 6 on the east-west direction and from the sample plots no. 1 on the north-south direction were analyzed. For the N-E edge, the values from the sample plots no. 1 on the east-west direction and from the sample plots no. 6 on the north-south direction were used (Figure 3). Results show that seedling sizes (height, root collar diameter and total aboveground biomass) in the southwest edge are significantly greater than those in the northeast edge of the plots (Figure 5, Table 11). These differences existed even before the beginning of the differentiated works (year 2017) and are preserved after their application for two growing seasons, up to the year 2019.

Table 11 The sizes and biomass of seedlings in the sample plots from the south-west and north-east edges of the gaps and the statistical significance of the differences between them (H – height, D_c– root collar diameter, BST – total aboveground biomass)

Variable	The year	SW average value	NE average value	t test (probability p)
H (cm)	2017	96.56	59.07	0.000
	2019	198.06	110.41	0.000
D_C (mm)	2017	9.95	6.55	0.000
	2019	19.45	11.80	0.000
BST (kg)	2017	0.08	0.03	0.000
	2019	0.46	0.11	0.001

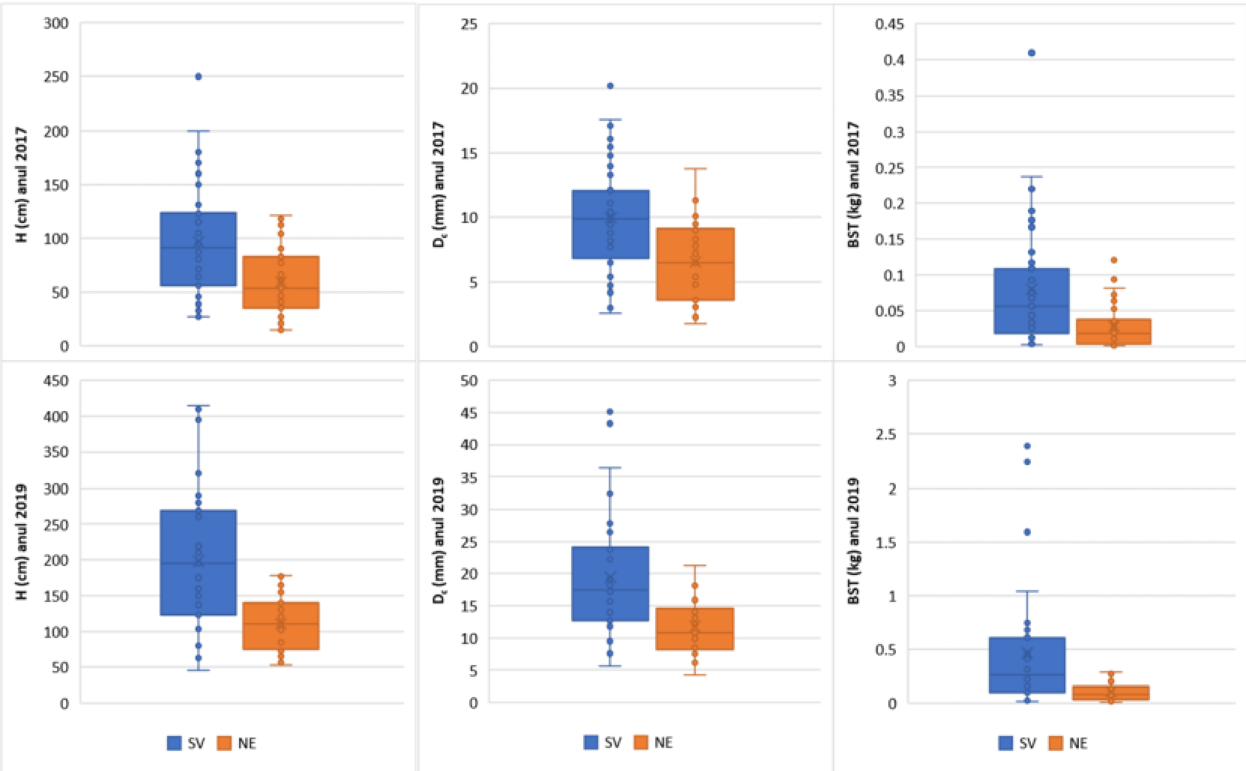

Figure 5 Comparative analysis of the dimensions of the five tallest pedunculate oaks in the sample plots corresponding to the south-west and north-east edges of the gaps. In all cases the differences are statistically significant - see Table 11 (H – height; D_c – diameter at root collar; BST – total aboveground biomass).

Discussions

Regarding the fertile edge of the gaps, the measurements carried out in 2017 on all pedunculate oak seedlings in the sample plots, at the level of all the gaps, before the beginning of the differentiated works (Ghinescu et al. 2022), showed that the dimensions of the seedlings (height and root collar diameter) increase from east to center, further west, the sizes being quite similar. In the case of the direction from north to south, the dimensional increase seems to continue beyond the central surfaces, towards those in the south (Ghinescu et al. 2022). So, the influence of the favorable lighting in the west during the morning and the temporary shelter provided by the southern edge during the hot periods of the day is noted. The same trend, and thus the fertile edge, is confirmed by the five tallest pedunculate oak seedlings from each area chosen here for analysis, both for the year 2017 and after two growing seasons in which differentiated tending works were applied. So the limiting factor in the area remains the dryness due to the intense heat during the growing season, the southwest part of the gap being well lit in the morning, but more sheltered at noon and afternoon, when the heat is excessive. In addition, regardless of the application of the tending works or not (including the control plots), the differences are preserved, confirming once again the fact that site factors have a determining role in the uneven distribution of the quality of the growth space at gap level and not just the competition, controlled by applied works. As such, the gaps should rather have an elliptical shape (major axis in the east-west direction) and the thinning of the portions between the gaps should be uneven (in the east more, to allow light to enter; in the west less, to limit as possible the adverse effect of heat). These results also confirm that, at present, the site conditions (deep river bed, lack of flooding, high dryness due to more atypical climatic conditions - more prolonged droughts compared to past decades) are more characteristic of a normal low plains (where the heat and dryness produced affects the growth of trees and, as such, the presence of linden and even hornbeam is normal - Pașcovschi 1967) and not a typical riparian stand, where the humidity would be more favorable due to flooding and therefore the presence of ash is natural). Moreover, the evolution of the composition of the stand in the last decades shows a similar trend: the proportion of ash has decreased, while that of hornbeam and linden has increased (Tables 1 and 3 in Ghinescu et al. 2022).

4.2.6. Effect of position within gaps

To analyze the effect of the position within the regeneration gaps, the data were accumulated on three areas: central, intermediate and edge. As such, the data for the central area comes from sample plots numbered 3 and 4 on both transects, those for the intermediate areas from sample plots 2 and 5 on both transects, and those for the edge areas from sample plots numbered 1 and 6 from both transects (Figure 3). Regarding the light regime, the results of the analysis of the hemispherical photos show that even at the edge the percentage of photosynthetically active light reaching the ground (PACL) is quite high (between 26.6% and 79.4%), with one exception (sample plot 1, from the edge, on the SN direction, gap no. 8), where the value is only 9.8%. This situation is also confirmed by the degree of canopy openness in these areas (between 16.9% and 44.3%; with one exception, the same edge area, with the value of 12.6%). Despite this fact, the cumulative data on all analyzed gaps shows that there is a clear difference in the growth of seedlings from the center to the edge (Figure 6, Table 12).

Table 12 The average values of the sample plots according to the position within the gap and the statistical significance of the differences between them (H – height; Dc – diameter at root collar; BST – total aboveground biomass; C - center; I - intermediate; M – edge; with bold numbers – statistically significant differences at a 95% confidence level)

Variable	Year	C	I	M	t test (probability p)	
H (cm)	2017	119.27	110.53	77.39	C vs. I	0.052
					C vs. m	**1.74E-11**
					I vs. m	**5.03E-08**
	2019	220.49	205.54	151.86	C vs. I	0.132
					C vs. m	**1.10E-07**
					I vs. m	**1.49E-05**
D_c (mm)	2017	11.34	10.71	8.21	C vs. I	0.126
					C vs. m	**1.09E-08**
					I vs. m	**1.74E-06**
	2019	19.79	19.40	15.41	C vs. I	0.655
					C vs. m	**2.18E-04**
					I vs. m	**4.23E-04**
BST (kg)	2017	0.10	0.09	0.05	C vs. I	0.093
					C vs. m	**6.96E-07**
					I vs. m	**1.68E-04**
	2019	0.52	0.40	0.27	C vs. I	**0.034**
					C vs. m	**0.001**
					I vs. m	**0.044**

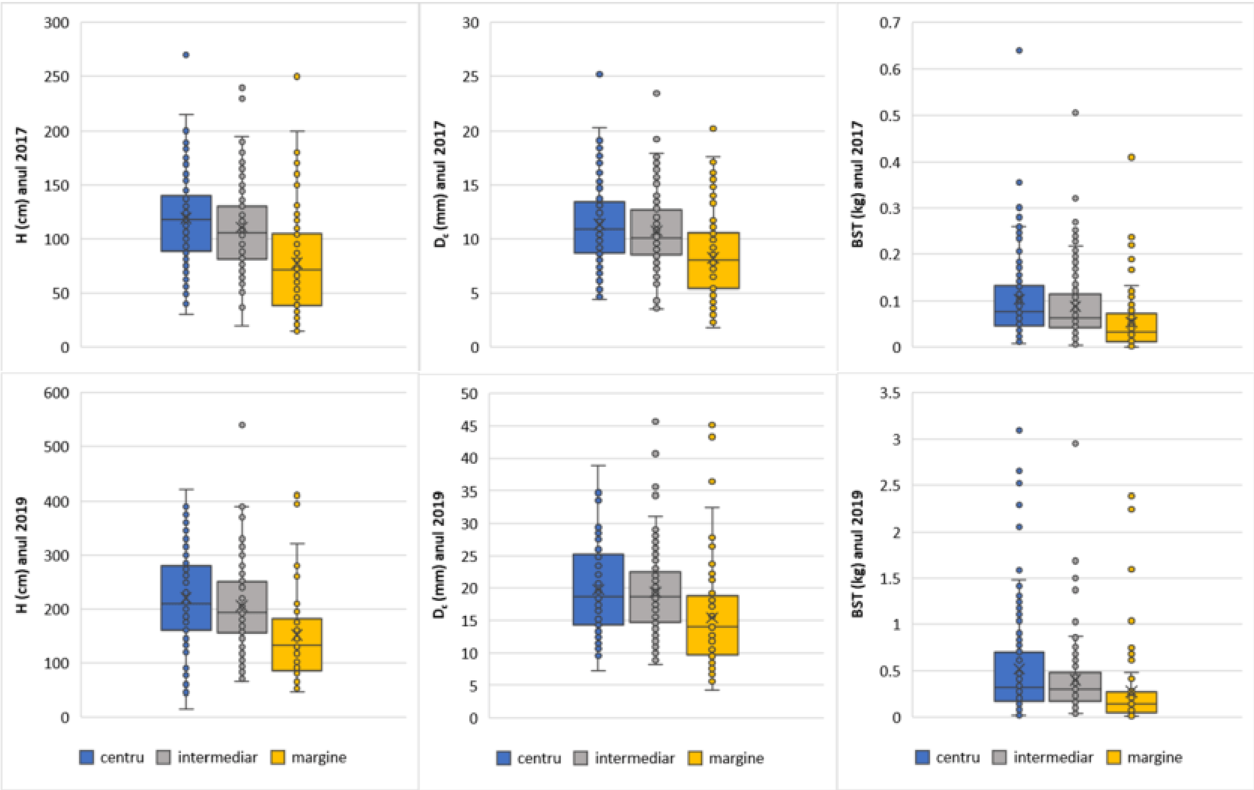

Figure 6 Comparative analysis of the dimensions of the five tallest pedunculate oaks from the sample plots related to the three areas: central, intermediate and edge (see Figure 2) (H – height; Dc – root collar diameter; BST – total aboveground biomass).

The differences between the two areas (central and edge) are always significant regardless of the measured variable (height, diameter and total aboveground biomass) also before the application of tending works in different ways (when the works were applied in the same way –cutting from ground level of competing vegetation), as well as after. Even if the differences between the central and intermediate zones are not significant in general, they do exist, with the central zone remaining the most favorable for growth. Regarding the differences between the intermediate and the edge area, significantly higher values of the measured variables are recorded in the first, both before and after the tending works. Therefore, it should be noted that these significant differences appear despite the fact that in the mature stand, between the gaps, the canopy cover was also reduced by cuttings.

Discussions

Regarding the effect of the position within the regeneration gaps, the results confirm the effect of the two types of competition described in the introductory part: only with the surrounding regeneration; both with the surrounding regeneration and with the mature trees still remaining in the stand. Thus, in the center, where the competition is only with the surrounding regeneration, growth is the most active (significant differences compared to the edge, where the above-ground part is smaller). Even if the stand between the gaps has been thinned (the light conditions at the edge are quite good - PACL generally greater than 50%; between 26.6% and 79.4%, with only one exception where the value is 9.8%) and edge regeneration has grown well (average edge heights are already 1.5m), competition with the mature stand still seems to play an important role. The differences observed here may also be due to the fact that, when the light reaching below the canopy represents less than 50% of the photosynthetically active radiation, regenerating pedunculate oaks invest more in the roots than in the aboveground part (Modrow et al. 2020). Other similar studies (Brezina and Dobrovolny 2011) showed that, also in sessile oak, for a vigorous growth in height, this parameter should reach values between 30 and 60%. In the case of the present study, in half of the edge sample plots where the hemispheric photographs were taken (6 out of 12), the PACL values were up to 50%, even though some values were close to this threshold (41.0 %, 47.9% and 48.2%). Although the hemispherical photographs were taken only in three gaps (1, 8 and 9), the regeneration cuts were applied similarly in the stand in the portions between the gaps, so the lighting regime is very likely similar in the case of the other gaps analyzed.

4.2.7. Effects of tending works applied in different ways

4.2.7.1. Within the central area of the gaps

The results show that, at the time of the beginning of the differentiated application of the tending works (year 2017), the pedunculate oaks in the central area of the gaps considered as "control" (in which no more tending works will be applied) had the largest dimensions (Table 13, Figure 7) . They were significantly taller than those in the gaps with breaking from 1/2 and significantly taller and thicker than the gaps with cutting from ground level. Moreover, the seedlings in the gaps where breaking from 1/2 was performed had significantly smaller sizes (and implicitly biomass) than those in the other gaps, where other types of work were to be done.

After carrying out the tending works in a different way (2019), the effect is clear: the seedlings from the breaking from 1/3 and cutting from the ground surface become significantly larger (in diameter and biomass) than those from the control plots, while the values from the gaps with breaking from 1/2 become close - they remain smaller, except for the diameter, but statistically nonsignificant.

Regarding possible differences between the three types of work, the pedunculate oaks from the gaps with breaking from 1/2, which were significantly smaller than those in which other works were to be done, remain smaller even after the works (so the tending works do not make such a big difference to help them recover the difference in 2 years).

Table 13 The sizes and biomass of the seedlings in the central area of the gaps depending on the work performed within the plot and the statistical significance of the differences between them (H – height; Dc– root collar diameter; BST – total aboveground biomass; M – control; 1/3 - breaking from 1/3; 1/2 – breaking from 1/2; from ground – cutting from the ground surface; in bold – statistically significant differences at a 95% confidence level)

Variable	Year	m	1/3	1/2	from ground	t-test (p-prob.)	
H (cm)	2017	142.93	130.29	83.98	121.53	M vs. 1/3	0.071
						M vs. 1/2	**3.25E-16**
						M vs. from ground	**0.014**
						1/3 vs. 1/2	**3.62E-10**
						1/3 vs. from ground	0.322
						1/2 vs. from ground	**1.25E-05**
	2019	193.37	285.50	174.38	233.32	M vs. 1/3	**6.63E-07**
						M vs. 1/2	0.208
						M vs. from ground	0.080
						1/3 vs. 1/2	**4.86E-13**
						1/3 vs. from ground	**0.014**
						1/2 vs. from ground	**0.004**
D_c (mm)	2017	12.67	12.53	8.65	11.69	M vs. 1/3	0.867
						M vs. 1/2	**5.00E-10**
						M vs. from ground	0.226
						1/3 vs. 1/2	**1.15E-05**
						1/3 vs. from ground	0.394
						1/2 vs. from ground	**1.22E-04**
	2019	16.45	26.65	16.78	24.89	M vs. 1/3	**7.33E-11**
						M vs. 1/2	0.756
						M vs. from ground	**0.001**
						1/3 vs. 1/2	**5.22E-12**
						1/3 vs. from ground	0.456
						1/2 vs. from ground	**7.69E-04**
BST (kg)	2017	0.13	0.13	0.05	0.12	M vs. 1/3	0.845
						M vs. 1/2	**1.73E-10**
						M vs. from ground	0.540
						1/3 vs. 1/2	**4.48E-06**
						1/3 vs. from ground	0.689
						1/2 vs. from ground	**4.80E-04**
	2019	0.27	0.77	0.24	0.79	M vs. 1/3	**3.19E-09**
						M vs. 1/2	0.450
						M vs. from ground	**0.001**
						1/3 vs. 1/2	**3.91E-10**
						1/3 vs. from ground	0.897
						1/2 vs. from ground	**0.001**

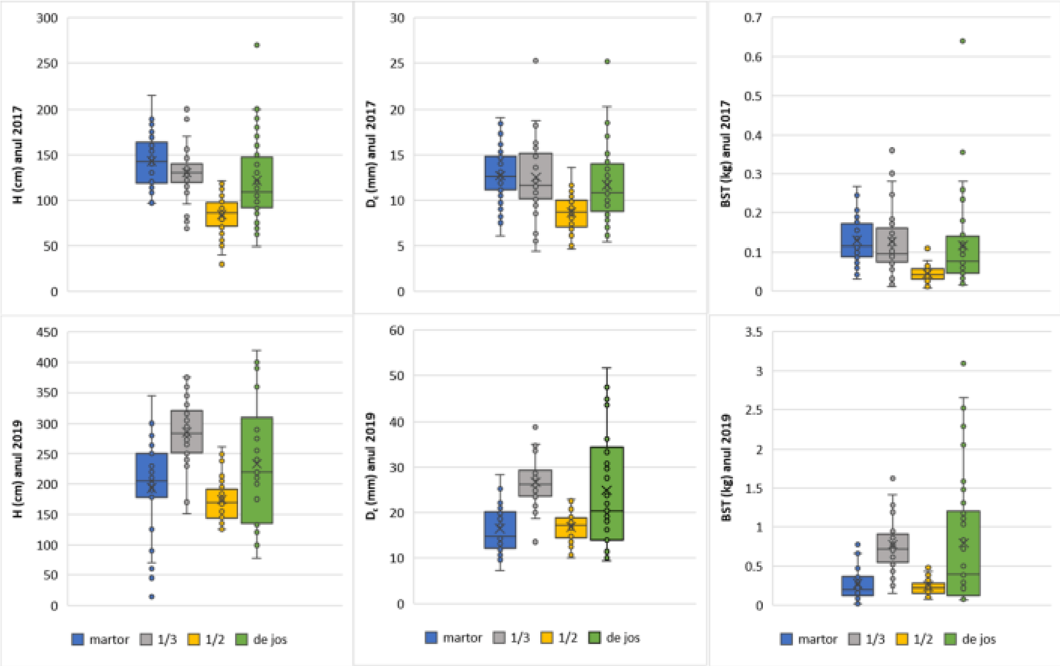

Figure 7 Comparative analysis of the dimensions of the five tallest pedunculate oaks from the central area of the gaps (H – height; Dc – root collar diameter; BST – total aboveground biomass; 1/2 – breaking from 1/2; 1/3 – breaking from 1/3; de jos - cutting from ground level).

In the gaps where the 1/3 breaking was to be done, the heights and diameters were higher in 2017 than in the gaps where the cutting from ground level was to be done, but with nonsignificant differences. After the works (in 2019) the pedunculate oaks in the first case (breaking at 1/3) become significantly taller than those in the gaps with the cutting from ground level. This is not surprising, as in the case of breaking from 1/3 the competing vegetation remains and is quite tall and as such stimulates the height growth of the pedunculate oaks. Regarding the diameter, the values remain higher in the case of breaking from 1/3, but the difference is still statistically nonsignificant, as it was in 2017. However, it can be seen from the graph (Figure 7) a greater number of trees in the case of cutting from the ground surface that register values well above average and above the trees in the gaps with breaking from 1/3. For biomass, the situation is similar to that of diameters, the difference being nonsignificant, although this time the average recorded in the plot with the cutting from ground level is higher than that of the gaps with breaking from 1/3. In addition, more trees are observed with much higher values than those recorded in the case of the breaking from 1/3. So, very likely over time, after repeating the tending works, the positive effects of cutting from ground level will be seen (significantly larger biomass and dimensions than when breaking from 1/3).

Discussions

We expected differences to be found as a result of the application of the tending works and this is evident in all cases compared to the control areas. Of course, the effect is partially masked by the very high variability existing before the start of the differentiated tending works (year 2017), otherwise characteristic of natural regeneration compared to plantations (where both the size of the seedlings, but especially the spacing, are much more uniform). Since in the middle of the gaps the influence of the trees from the edge (competition with the mature trees, which are much taller and with a much better developed root system) is nonsignificant, the competition with the other seedlings from the regeneration produces obvious effects. Regarding the various ways of applying the tending works, it seems that in the central zone (where the light is sufficient - PACL > 60%) they do not produce significant growth differences, or at least not in the short term, although there is a tendency that cutting from ground level leads to better developed trees (i.e. individuals with higher biomass) than in the other two cases.

Regardless of the tending work type (including in control areas), the growth of pedunculate oaks is particularly active, the heights reached after 7 years from the initiation of the regeneration process being, on average, 2 m, with many values even higher. In these areas, where the influence of the mature stand is no longer felt, it is not expected that the subsequent cuttings (to widen the gaps and to connect them) will bring a significant contribution. Therefore, their application or delay in their application has no effect.

4.2.7.2. In the intermediate area of the gaps

In 2017, before the differentiated application of the tending works, the pedunculate oaks in the control areas had the largest dimensions, as in the case of the central areas (Figure 8). They, however, have similar dimensions (statistically nonsignificant differences) to those in the gaps in which breaking from 1/3 was to be made, but significantly larger than in those in which breaking from 1/2 was to be made (Table 14).

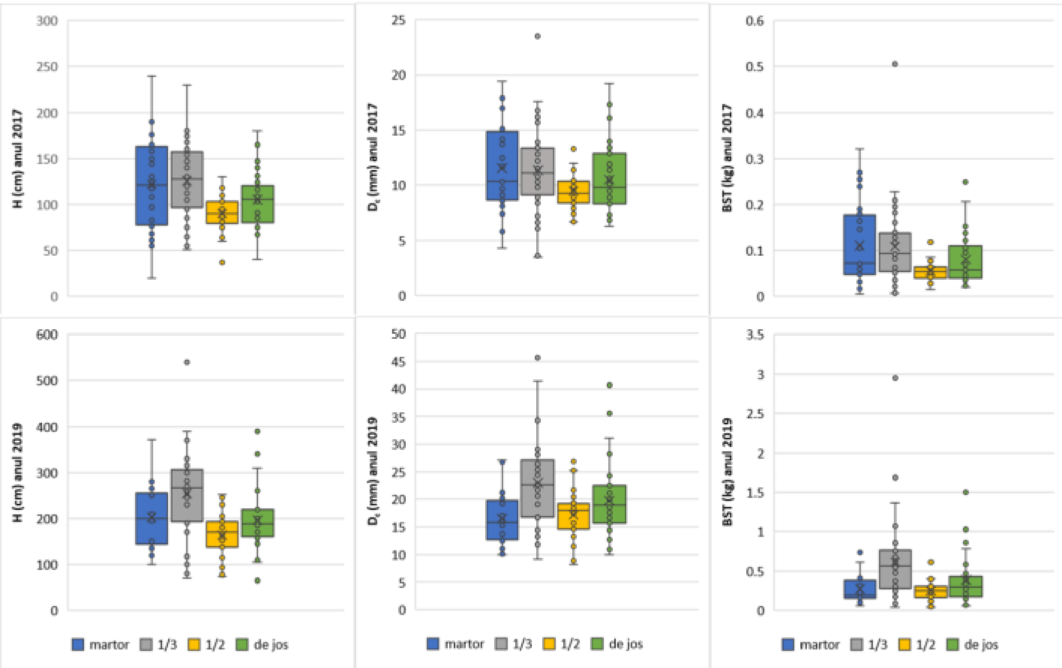

Figure 8 Comparative analysis of the dimensions of the five tallest pedunculate oaks from the sample plots from the intermediate area of the gaps according to the works performed (H – height; Dc – diameter at the root collar; BST – total aboveground biomass; 1/2 – breaking from 1/2; 1/3 – breaking from 1/3; de jos - cutting from ground level).

Table 14 The average values in the intermediate zone of the gaps depending on the work performed within the gap and the statistical significance of the differences between them (H – height; Dc – diameter at the root collar; BST – total aboveground biomass; M – control; 1/3 - breaking from 1/3; 1/2 – breaking from 1/2; from ground - cutting from ground level; with bolded figures – statistically significant differences at a 95% confidence level)

Variable	Year	M	1/3	1/2	from ground	t-test (p-prob.)	
H (cm)	2017	121.88	125.78	89.92	105.15	M vs. 1/3	0.721
						M vs. 1/2	**0.001**
						M vs. from ground	0.102
						1/3 vs. 1/2	**5.59E-06**
						1/3 vs. from ground	**0.013**
						1/2 vs. from ground	**0.010**
	2019	202.36	254.34	163.51	196.86	M vs. 1/3	**0.011**
						M vs. 1/2	**0.015**
						M vs. from ground	0.747
						1/3 vs. 1/2	**1.60E-06**
						1/3 vs. from ground	**0.003**
						1/2 vs. from ground	**0.015**
D_c (mm)	2017	11.57	11.36	9.48	10.52	M vs. 1/3	0.826
						M vs. 1/2	**0.007**
						M vs. from ground	0.219
						1/3 vs. 1/2	**0.008**
						1/3 vs. from ground	0.290
						1/2 vs. from ground	0.062
	2019	16.50	22.99	17.22	19.75	M vs. 1/3	**9.35E-05**
						M vs. 1/2	0.538
						M vs. from ground	**0.028**
						1/3 vs. 1/2	**1.70E-04**
						1/3 vs. from ground	0.056
						1/2 vs. from ground	0.061
BST (kg)	2017	0.11	0.11	0.06	0.08	M vs. 1/3	0.915
						M vs. 1/2	**0.001**
						M vs. from ground	0.088
						1/3 vs. 1/2	**6.37E-04**
						1/3 vs. from ground	0.097
						1/2 vs. from ground	**0.016**
	2019	0.27	0.61	0.25	0.39	M vs. 1/3	**0.001**
						M vs. 1/2	0.559
						M vs. from ground	0.094
						1/3 vs. 1/2	**1.60E-04**
						1/3 vs. from ground	**0.028**
						1/2 vs. from ground	**0.021**

As in the case of the central areas, the seedlings in the gaps with breaking from 1/2 were generally significantly smaller than those in the other gaps where the other types of work were to be done, except for the diameter (insignificantly smaller than the one from gaps with cutting from ground level).

After the works (2019), the effect is not as clear as in the case of the central areas. The situation changes in the case of the diameter, where the values in the areas with breaking from 1/3 and those with cutting from ground level become significantly higher than in the control, and those in the areas with breaking from 1/2 recover part of the difference, which becomes nonsignificant. These changes are somewhat reflected in the above-ground biomass, where only the values from the surfaces with breaking from 1/3 are significantly higher, while those from the surfaces with breaking from 1/2 recover from the difference, which becomes nonsignificant.

Regarding the differences between the tending works, initially (2017) the pedunculate oaks from the areas with breaking from 1/2 had the smallest dimensions, generally significantly smaller than those where the other types of work were to be carried out. These remained the same even after the tending works, so these works do not produce such a big effect to help them recover the difference in 2 years. In the areas where breaking from 1/3 was to be done, the heights and diameters were higher in 2017 compared to the plots where cutting was done from ground level (significant differences in heights and nonsignificant in diameters and biomass). After the works (in 2019), the situation remained unchanged for diameter and height but, surprisingly, for the above-ground biomass, the pedunculate oaks in the first case (breaking from 1/3) register significantly higher values than those in the gaps with the cutting from ground level.

Discussions

Considering that, in these sample plots, in addition to the competition with the surrounding regeneration, that with the mature stand also begins to be felt, it is expected that the differences will not be as sharp as in the extreme cases (central surfaces - only competition with surrounding regeneration; edge surfaces – competition mostly with mature trees). Thus, the transition between the two areas (the center area of the plot and the edge area) is actually confirmed. Despite this fact, as observed in the present study, the sizes of seedlings in the intermediate zone are close to those in the central zone of the gap, even if competition with the mature stand begins to be felt. As such, the importance of applying tending works is even greater.

4.2.7.3. In the edge area of the plot

Before the differential application of the works (year 2017), the pedunculate oaks in all gaps, in the edge areas, had similar dimensions (the differences recorded between the average heights and diameters and, implicitly, the biomass of the trees, were statistically nonsignificant). So, there was no statistically significant difference between the control plots and those where differential works were to be applied (Figure 9, Table 15).

After the works were carried out (2019), the situation remained similar. Although, in the case of the diameter, in the gaps with breaking from 1/3, a significant difference compared to the control appeared (the average in the control is significantly lower), this is due to some extreme values (three values) without which the differences become nonsignificant. The same happens in the case of biomass, where the pedunculate oaks from the same plots (with breaking from 1/3) have significantly higher values than those from the control plots. Here too, however, if the two extreme values (the highest) are excluded, the differences become nonsignificant.

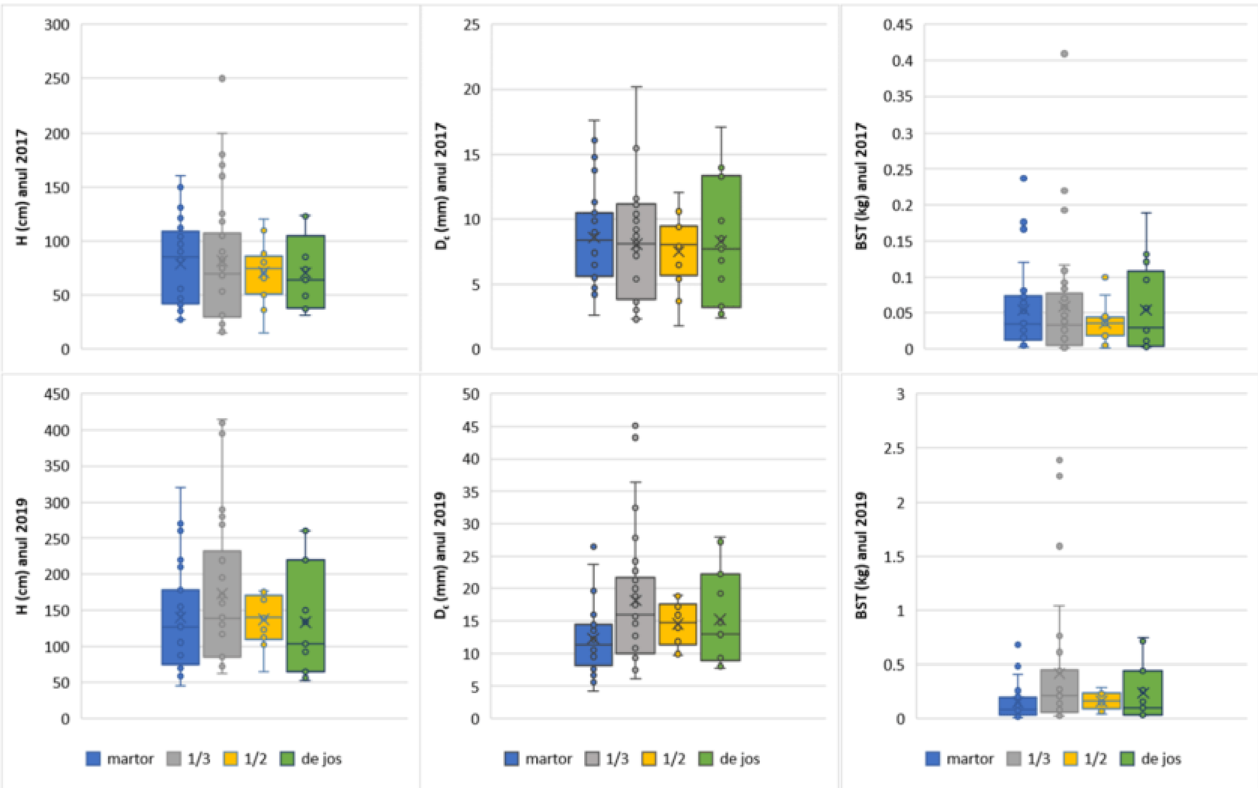

Figure 9 Comparative analysis of the dimensions of the five tallest pedunculate oaks from the sample plots from gap edge area according to the works performed (H – height; Dc – diameter at the root collar; BST – total aboveground biomass; 1/2 – breaking from 1/2; 1/3 – breaking from 1/3; de jos - cutting from ground level).

Table 15 Average values in the edge area of the gaps depending on the work performed within the gap and the statistical significance of the differences between them (H – height; Dc – root collar diameter; BST – total aboveground biomass; M – control; 1/3 - breaking from 1/3; 1/2 - breaking from 1/2; de jos - cutting from ground level¸ statistically significant differences at a 95% confidence level)

Variable	Year	M	1/3	1/2	from ground	t-test (p-prob.)	
H (cm)	2017	78.57	81.55	70.67	70,31	M vs. 1/3	0.811
						M vs. 1/2	0.483
						M vs. from ground	0.504
						1/3 vs. 1/2	0.416
						1/3 vs. from ground	0.433
						1/2 vs. from ground	0.978
	2019	139.74	173.03	136.80	133.18	M vs. 1/3	0.179
						M vs. 1/2	0.880
						M vs. from ground	0.820
						1/3 vs. 1/2	0.112
						1/3 vs. from ground	0.205
						1/2 vs. from ground	0.894
Dc (mm)	2017	8.60	8.08	7.51	8.28	M vs. 1/3	0.606
						M vs. 1/2	0.316
						M vs. from ground	0.837
						1/3 vs. 1/2	0.611
						1/3 vs. from ground	0.899
						1/2 vs. from ground	0.635
	2019	12.30	18.15	14.56	15,24	M vs. 1/3	**0.012**
						M vs. 1/2	0.160
						M vs. from ground	0.275
						1/3 vs. 1/2	0.100
						1/3 vs. from ground	0.336
						1/2 vs. from ground	0.794
BST (kg)	2017	0.05	0.06	0.04	0.05	M vs. 1/3	0.788
						M vs. 1/2	0.184
						M vs. from ground	0.999
						1/3 vs. 1/2	0.177
						1/3 vs. from ground	0.830
						1/2 vs. from ground	0357
	2019	0.15	0.42	0.16	0.24	M vs. 1/3	**0.031**
						M vs. 1/2	0.834
						M vs. from ground	0.364
						1/3 vs. 1/2	**0.034**
						1/3 vs. from ground	0.204
						1/2 vs. from ground	0.400

Regarding the differences between the tending works, before their application (year 2017), the pedunculate oaks in all gaps had similar dimensions in the edge areas (the differences recorded between the average heights and diameters and, implicitly, the biomass of the trees were statistically nonsignificant). So, there was no statistically significant difference between the gaps where differential tending works were to be applied. After the tending works were carried out (2019), the situation remained similar. Although, in the case of biomass, in the gaps where breaking from 1/3 was applied a significant difference appeared compared to those with breaking from 1/2, where the average is significantly lower, this is due to some extreme values (two values) without which the differences become nonsignificant.

Discussions

Although we expected differences in growth following application of the tending works, this was not evident in any case, even compared to the control areas. This situation is very likely due to the fact that, at the edge, competition with the mature stand dominates, competition that is not affected by the tending works (they only control the competition with regeneration). As such, the effect of the tending works on competition is greatly reduced, with the works controlling only the competition with other trees in the regeneration, not with the large ones. However, the lack of tending works is not recommended, at least in the beginning, as the competition with the surrounding regeneration as well as with the mature trees left standing seems to have a negative influence on the survival of the pedunculate oaks. The number of seedlings present in the areas on the edge is generally lower compared to the others (for example, the average number is only 8.7 seedlings per sample plot, compared to the intermediate and center plots where we find 14.2 and respectively 13.1 seedlings on the sample plot).

However, it should be noted that, regardless of the tending work type (including in the control areas), the growth of pedunculate oaks is active even at the edges of the gaps, the heights reached after 7 years from the initiation of the regeneration process being around 1.5 m, with some values even higher. In these areas, it is expected that the subsequent cuts (to widen the gaps, respectively to connect them), which will remove the competition from large trees, will bring an important contribution to the growth. On the other hand, even if the delay in their application has a more negative effect on the accumulation of biomass and does not lead to the disappearance of the already tall enough regeneration, the damages that will be caused during the harvesting will be much more difficult to avoid and to repair (the ability to recover after, even for damaged seedlings which are to be cut to ground level, being more difficult than in the case of small seedlings).

5. Conclusions. Original contributions. Recommendations for practice. Future research.

5.1. Conclusions

The information presented below comes from the papers published according to the requirements of the PhD program:

- " Surprinzătoarea simplitate a tratamentelor adecvate stejăretelor pure și amestecurilor cu stejar " (authors Nicolescu V.-N., Ghinescu MN, Mihăilescu, Gh.), year 2021, Bucovina Forestiera 21(2): 183-197
- " Regenerarea naturală într-un șleau de luncă din Ocolul silvic București" (authors Ghinescu, M.-N., Nicolescu, V.-N., Stăncioiu, P.-T.), year 2022, Bucovina Forestiera 22(1) : 7-20.
- " Evoluția regenerării naturale de stejar pedunculat într-un șleau de luncă din Ocolul silvic București în contextul aplicării degajărilor prin metode diferite" (authors Ghinescu, M.-N., Stăncioiu, P.-T.), year 2024, Bucovina forestieră 24 (2): (accepted for publication).

5.1.1. The potential for natural regeneration in mixed species riparian stands after the application of group shelterwood cuts

After 5 years from the initiation of group shelterwood cuttings, the regeneration in the open gaps is very good (the number of seedlings per hectare is high), both with regard to the pedunculate oak (the main species) and the other species characteristic of riparian mixed species stand. So, we can conclude that the prompt opening of the gaps and the thinning of the stand between the gaps are basic conditions for the proper exploitation of seed mast years, very rare events nowadays. Also, the consistent application of tending works from the beginning is indispensable to control the competition within the installed regeneration and to ensure a good participation for the pedunculate oak. The present research shows that under such conditions (of consistent application for five years tending works by cutting unwanted seedlings from ground level), oak seedlings seem to overcome the difficult period characteristic of the initial phase, in which they can be eliminated by other competing species. The development and survival of the species in the control plots (where for 3 growing seasons no further work was applied) shows that the seedlings are already coping with the competition with the other species. In addition, the proportion of oaks in the composition shows that the tending works are leading the stand towards a mixture dominated by oak and therefore the succession mentioned by the previous literature (Pașcovschi 1967) observed in the past due to anthropic interventions (coppice with reserves, leaving old reserves) is no longer currently produced.

The uneven distribution of oak in the surface of the analyzed gaps (the proportion in the composition is quite variable in the analyzed sample plots) is natural in the case of natural regenerations and especially in mixtures such as the riparian mixed species stand. These two realities (variable proportion and uneven distribution) underline the obligation to continue applying the tending works to help the development of natural regeneration, in order to ensure a satisfactory participation of pedunculate oak in the future stand (in competition with those species which are faster-growing and more shade tolerant, such as hornbeam and silver linden). The biometric characteristics of the oak seedlings (5 years after the installation of the regeneration) support these conclusions, confirming the sensitivity of the species to light as a growing factor (the average diameter at the root collar is lower than that of other species, but the average height is higher), as well as the success of natural regeneration tending works applied up to the time of research.

Although the studied stand is in the riparian area, the hydrological regime is not (anymore) a typical one both due to the deepening of the Sabar River bed (a fact that prevents the occurrence of periodic floods, typical for the floodplains and favorable for ash trees), as well as the characteristic climatic changes of recent years, which have led to periods of prolonged drought (little snow in winter, low precipitation in spring, drought in summer). As such, the reduced participation of ash in the composition of the regeneration is not surprising and the reduction of its proportion in the composition of the future stand is natural. The higher proportion of linden and hornbeam (than that characteristic of a typical riparian mixed species stand) reinforces those observed by research and shows a succession towards a low plain mixed species stand.

5.1.2. Dynamics of growth and development of natural seedlings in meadow sloughs

The analysis of the sizes recorded by the oak seedlings within the regeneration gaps (both in 2017 and in 2019, after the differentiated application of tending works), indicates the south and west side (more protected from solar radiation during critical periods of the day) as being more favorable (the "fertile" edge of the gap). So, in the studied stand, heat (dryness) is rather the most limiting factor and not light or competition in the soil with the roots of the mature stand. Thus, the research confirms what was said previously (subchapter 5.1.1.) regarding the existence of conditions more typical of the low plain than the typical floodplain.

Regarding the planning of the regeneration process, the present research shows that, after only five years from the start of the regeneration cuts, the oak seedlings, but also of other species in the riparian mixed species stand analyzed, have already reached sizes larger than those recommended of the forestry technical norms (15-40 cm - Anonymous 2000) for the application of final removal cuts. This is also confirmed by the provisions of the new forest management plan, which already proposes cleaning in the regeneration clumps installed within the gaps. On the other hand, even if the regeneration has generally grown well even at the edge of the gaps (average heights at the edge being already 1.5 m), here the competition with the mature stand still plays an important role (confirmed by the significant dimensional differences compared to regeneration from the center of the gaps). As such, the remarkable dimensions (reached even in the areas on the edge of the gaps) underline not only the importance and usefulness of the interventions made in the portions between the gaps (extraction of mature trees through which the canopy was opened and the penetration of a greater amount of light was possible) and the tending works from the gaps but at the same time also the need to remove the mature trees left standing. Delaying the final removal cuts could jeopardize the development of oak regeneration and even its existence in the future stand, disadvantaged compared to shade-tolerant species such as hornbeam and linden. Therefore, in favorable conditions for the installation and development of the natural regeneration of the pedunculate oak, the application of the treatment "according to the book" (with long regeneration periods, of 15-30 years (Anonymous 2022b)) can lead to rather negative effects on the quality of young stands and, therefore, to the inefficient use of the occasions, increasingly rare, in which not only the seeding of the pedunculate oak is sufficient for the establishment of a natural regeneration, but also the site conditions are favorable for a vigorous subsequent growth. Similar studies (Annighöfer et al. 2015) support this idea by showing that the presence of a large number of seed trees is important to ensure the establishment of regeneration but further, for its development (as the seedlings grow) the light becomes a limiting factor and the mature tree must be removed.

If it is desired to obtain more or less diversified structures, usually obtained by imposing long regeneration periods, they can be obtained through subsequent works (retention of mature seedlings, differentiated works in terms of intensity, installation of regeneration in gaps through plantations or seedings), after large trees intended to be extracted have been removed. Moreover, the transformation towards vertically diversified structures (relatively unevenaged) is indicated to be started in younger stands, where the mature stand is still viable (Schütz 2001), in order to be present in the structure until the installation of other successive cohorts (and therefore for the structure to become truly diversified and remain so), an operation that takes a long time.

Regarding the differentiated application of cleaning-respacing, regardless of the type of work applied in the last three seasons (including in control areas), the growth of pedunculate oaks is particularly active, the heights reached since the initiation of the regeneration process being on average 1.5 m at the edge gaps, in the central areas, the values being even higher (on average approx. 2 m, but with many values above). However, at the edge area of the gaps, since no significant differences appear between the tending works (the exceptional values in the case of the gaps with breaking from 1/3 existing before, therefore not being an effect of the work itself), the application of the cheapest method seems to be sufficient, until the residual mature stand is removed. On the other hand, in the central area of the gaps, where the competition is only with the surrounding regeneration, the tending works have the most visible effect compared to the situations where no works are applied, i.e. the control surfaces. We can say, therefore, that their application is not optional. In fact, recent studies (Mölder et al. 2019) show that the timely application and at the proper time of care works is one of the most important factors for obtaining valuable stands of pedunculate oak. Regarding the type of work, in this case too, no statistically significant differences can be seen between the different types of tending works. As such, here too one can opt for any of them. However, it should not be ignored that the cutting from the ground surface, as expected, seems to lead to better developed trees (the exceptional values, especially in terms of biomass, are clearly superior to those of the other works) than in the other two cases. These differences are expected to become significant over time. So, if the goal is to attain rapid growth in both height and diameter (vigorous trees), such tending work is necessary, despite the higher costs.

5.2. Original contributions

During the six years of research, the following was achieved:

- An up to date analysis of the current state of knowledge based on the existing literature regarding riparian mixed species stands, their evolution over time and the particularities of their way of regeneration through silvicultural treatments;
- Installation in the field of 96 sample plots (in 8 different regeneration plots) where a total of 18,633 seedlings of the main tree species were measured annually for three growing seasons (diameters at the root collar, height and annual growth);
- Recording and laboratory analysis of 34 hemispheric photographs;
- Rigorous processing and analysis of field data, their synthesis, information that formed the basis for the elaboration of the doctoral thesis, but also of the three publications produced within the doctoral program.

As a result of these efforts, through the research carried out in this doctoral thesis, the following contributions were made to the knowledge and management of riparian mixed species stands in Romania:

- Carrying out a comparative analysis of three types of application of cleaning-respace works on the evolution of natural regeneration in riparian mixed species stands;
- Carrying out a comparative analysis of the evolution of natural regeneration from riparian mixed species stands in various areas of the gaps;
- It was demonstrated the importance of opening the crown between the gaps to ensure the success of the regeneration of pedunculate oak in the fight with secondary species (especially at the edge of the gaps) and to make the most of the seed mast years;
- The possibility of obtaining a vigorous and independent regeneration in a much shorter regeneration period than the classic one, proposed by the technical norms in force, was demonstrated.

5.3. Recommendations for practice

Based on the research undertaken and the results obtained, some recommendations can be formulated for the forestry practice in the riparian mixed species stand in the south of the country. These are outlined below (in bold):

1) **In years of seed mast in pedunculate oak, regeneration gap size under group shelterwood cuttings can, and should, exceed 1.5-2.0 tree heights**.
2) In the current context (summers with very high temperatures, severe dryness) even in stands in floodplain areas (especially when riverbed is lowered and/or river is dammed) **an elliptical shape is recommended for the regeneration gaps, with the large axis in the east-west direction** .
3) Regarding the type of work, for **the edge area (where the competition with the remaining large trees dominates), since no significant differences appear between the tending works, the application of the cheapest method seems to be sufficient, until the removal of the residual mature stand. However, in the central area of the gaps, where the competition is only with the surrounding regeneration, even if one can opt for any of them, the cutting from ground level method is recommended, as it leads to better developed trees**.
4) **It is recommended that the regeneration period be reduced to less than 10 years where conditions and progress of regeneration (active growth) require this**.

5.4. Future research

To strengthen the conclusions and formulate broader recommendations, it would be useful to extend the research to more regeneration gaps and other riparian mixed species stands, as well as to monitor the effect of the tending works over longer periods. The relatively short time available as well as the limited resources (especially regarding the field measurement effort) did not make this possible in this PhD thesis.

The high variability encountered, which is otherwise characteristic of natural regenerations (gradually installed, over long periods of time) can mask the effects of certain factors (such as in this case maintenance works). As such, to validate the findings and/or improve knowledge in this area, it is recommended that a larger number of replications (gaps with different work types) be included in future research. Also, tagging seedlings from sample plots, although greatly increasing the field effort, would help with more detailed analyzes of the growth and survival of established seedlings in regeneration as well as identifying seedlings that may appear along the way between seed mast years (and thus explain differences due to age).

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