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Ways to use silver birch *Betula pendula* Roth regeneration in sites considered for stand conversion due to decline of Norway spruce *Picea abies* (L.) H. Karst. in the Silesian Beskid Mountains

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Abstract. One of the tree species appearing after a decline of Norway spruce *Picea abies* (L.) H. Karst. in the Silesian Beskid Mountains is Silver Birch *Betula pendula* Roth. Therefore our study was aimed at evaluating this birch regeneration and the dynamics of changes resulting from experimental cutting. Measurements and inventories of trees were conducted on research plots located in a ten-year old birch regeneration site with either no cutting, partial cutting (50%) or clear cutting (100%) of birch. We observed an introduction of biocenotic species (rowan, willow, aspen) as well as the target species (spruce, fir, beech) under the birch canopy. Fir and beech were also planted, because of their slow natural regeneration. The clear cut treatment caused a great number of sprouts growing from birch stumps, reaching a height of about 2 m over 3 years, resulting in competition with the regeneration of other species. Partial cutting did not cause such a drastic amount of sprouting. Furthermore, we found that only the spruce height increment is significantly less under a birch canopy compared to open space. The obtained results indicate a necessity to adjust the density and species composition of regenerating tree species under a birch canopy, avoiding complete removal of the first generation birch cover and the need to moderately thin out birch.

Keywords: decline in forest area, conversion, natural regeneration, Silesian Beskid Mts., Silver Birch

1. Introduction

As a result of the large-scale dieback of spruce in the Beskid Mountains over the last dozen or so years, extensive open spaces have emerged. The conditions there differ from forest interiors, and are additionally varied by the configuration of the terrain, the spatial variability of habitats, or the mountain climate with its parameters dependent on slope exposure and elevation above sea level. In general, the conditions for initiating and developing regeneration are extremely difficult (Szabla 2004; Ambroży 2010; Bruchwald, Dmyterko 2010). Nevertheless, a strong tendency towards natural regeneration of post-dieback woodland areas is observed in the Beskid forests, which is supported by the activities of foresters. Each regeneration is desirable, as it protects the soil from erosion and guards against the expansion of those plant species, which impede the initiation of forest species' regeneration after the stands are destroyed. Such regeneration requires silviculture methods that will enable future stands to meet protection and production needs (Ambroży 2010; Ambroży, Kosibowicz 2012).

Birch regeneration after a stand disaster is one of many categories of renewal occurring in such areas. The significant differences of birch regeneration in post-disaster areas were described by Drobyshev (2001), Jonášová and Prach (2004), Jonášová and Matějková (2007), Heurich (2009), Kulla et al. (2009), Ambroży and Kosibowicz (2012), Bednařík et al. (2014) and Martiník et al. (2014). The regeneration mainly differs in the way it starts, the advancement of its development, and species composition. Many authors have emphasized the positive role of spontaneous regeneration on different habitats (Silver Birch *Betula pendula* Roth, Rowan

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Sorbus aucuparia L. and Norway Spruce *Picea abies* (L.) H. Karst) in the phased process of reaching the proper species composition (Hawryś, Batko 1994; Ceitel 1994; Ceitel, Iszkuło 2000; Ambroży 2010; Löf et al. 2010; Ambroży, Kosibowicz 2012; Matl 2015).

When birch enters deforested areas, it is characterized by a significant rate of increase in diameter and height, especially when young. These rates are generally higher than those of most species coexisting with the birch (Ceitel, Iszkuło 2000; Zhukovskaya, Ulanova 2006; Ambroży 2010). This characteristic of birch is one of the main factors that makes its communities useful in regenerating areas affected by disasters, especially in the context of introducing target species under its canopy (Ambroży 2010).

The colonization by birch communities of some of the areas affected by the die-back in the Silesian Beskid region is therefore an opportunity to quickly transform the species composition into one appropriate to the requirements of the habitat. To make this possible, studies have been undertaken to determine the impact of applied silviculture treatments on the occurrence and growth of the natural regeneration of birch and other tree species in selected sites. This will allow us to develop breeding methods relating to birch regeneration in post-disaster areas adapted to the actual state of the regeneration.

2. Materials and methods

2.1. Description of the experiment

The regeneration of Silver Birch was studied in areas formed by spruce die-back in the Silesian Beskid Mountains. In the research area, this species occurs in dense stands occupying large areas of regeneration in the lower and middle segments of the lower montane zone, up to about 850−900 m a.s.l. In higher locations, birch regeneration is characterized by scattered groups and individual trees.

Three study sites were selected in the dense birch regeneration zone, which had a mean age of 10 years (9−11). The location of the sites is presented in Table 1.

The regeneration areas occurring in the study sites were subjected to experimental cutting. In study site 1, five strips, each about 30 m wide were delineated, running along the contours. All the birch were cut on two of the strips, 50% of the birch was cut from one strip, and two strips were left untouched. In study site 2, five strips were also delineated, running along the contours, at the same width as in the previous site. Birch regeneration was completely removed from three strips and two were left without any treatment. The third study site had three strips of about 30 m width, running perpendicular to the contours. All the birches were cut from one strip, about 50% of the total number of birches were cut from the next strip, and the last one was untouched. Work at study site 1 started before the 2013 growing season, while work at study sites 2 and 3 began in the corresponding period of 2014.

One research plot was established in each of the 13 strips. All plots were in the shape of a square having a 20 m side, with permanently stabilized corners. Within each plot, sub-plots were delineated to inventory the specific development phases of the renewal (Fig. 1).

2.1. Measurements and data processing

Measurements and observations were made according to a uniform methodology on the established research plots. In

Table 1. Location of the study sites

Site number	Location	Altitude range a.s.l. [m]	Exposition	Forest habitat type*
1	Forest District: Węgierska Górka Forest Unit: Sikorczane Section: 193 a	730–780	NE	LMGśw
2	Forest District: Węgierska Górka Forest Unit: Skrzyczne Section: 41 a	860–900	N	LMGśw
3	Forest District: Wisła Forest Unit: Czarne Section: 8 d	740–760	SW	LMGśw

***LMGśw** / fresh mountain mixed broad-leaved forest

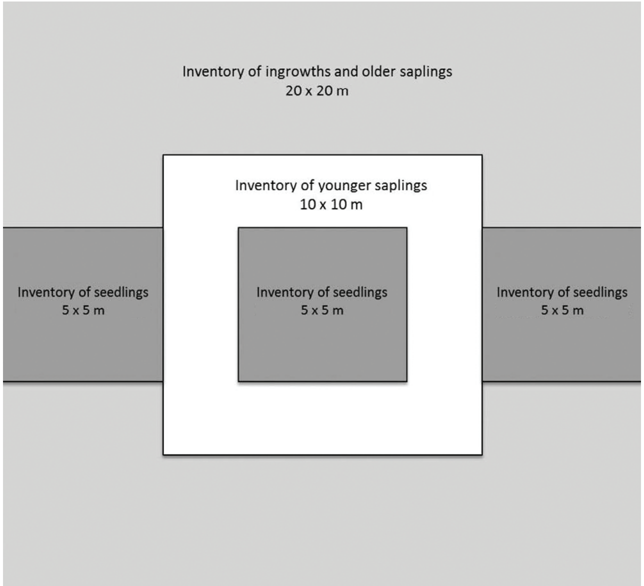

Figure 1. Scheme of subplots location on research plot

order to determine the changes taking place in the regeneration occurring in the research plots, measurements were made in two cycles. The first measurement of the plots located within study site 1 was made in the spring (April, May) of 2013, whereas plots located within sites 2 and 3 were measured in the corresponding period of 2014. A second measurement of the plots located in all three sites was taken after the end of the 2015 growing season (September, October).

The work carried out in the research plots included:

• Conducting an inventory of tree species in all developmental phases: seedling (planted and self-seeded trees up to 0.5 m), younger saplings (planted and self-seeded trees with a height of 0.5 to 1.3 m), older saplings (planted and self-seeded trees from 1.3 m of height to a diameter at breast height − DBH − of 7.0 cm), and ingrowths (trees with a DBH over 7.0 cm). An inventory of older saplings and trees forming the ingrowth (if present) was conducted throughout the entire research plot (400 m^2). An inventory of younger saplings was conducted in the sub-plots, which had an area of 100 m^2, while the inventory of seedlings covered an area of 75 m^2.

• DBH measurements were made of tree species exceeding a height of 1.3 m (older saplings, ingrowth) in single-centimetre diameter classes.

• Height measurements were made of all species represented in a given plot by regeneration development phase. For each species occurring in a given phase, the height of 20 tress was measured. If a species had a lower number of trees in a particular development phase, all of them were measured.

• The height increment of the last three years of 30 Norway spruce was measured.

During the spring measurements, the just initiated current height increment of the trees was not considered.

The results obtained from the inventory and field measurements were presented for each study site and experimental variant. The analysed characteristics of the regeneration (species composition, density, mean height and mean height increment) were presented for all variants of the experiment only in the second test due to the need to reduce the scope of work. When calculating the average height of all renewals of a particular tree species, the number of trees in each development class was used as a weight.

The effect of cutting intensity on the height increment of spruce regeneration was assessed using the Kruskal-Wallis test from the Statistica 10 statistical package, with an assumed significance level of $\alpha = 0.05$.

3. Results

3.1. Structure of the regeneration with Silver Birch

In the three years since the removal of all birches (experimental variant 1), birch continued to have the highest share in the species composition of seedlings and saplings (Table 2) as a result of the growth of stump shoots. However, they did not attain a size that allowed them to be categorized as ingrowth. The ingrowth consisted of the largest sizes of spruce. Within two years of clear cutting all the birch in the analogous experimental variant in study site 2, spruce dominated in the species composition of the regeneration, while birch sprouts had the highest share of younger saplings. At the third study site, birches dominated the other species in numbers in the older sapling phase two years after the treatment.

In the second variant, where about 50% of the total number of birches (study sites 1 and 3) were removed, this species dominated in the ingrowth layer. The proportion of birches was smaller for seedlings and saplings than the share of the most numerous regeneration species (spruce, fir).

For the third variant, where no cuts were made, the topmost layer comprised of birch regeneration as well as other species in all study sites. Most of the other species entered the area spontaneously in between the birches and under its canopy, and only the predominating numbers of fir *Abies alba* Mill and beech *Fagus sylvatica* L. were artificially renewed. Spruce comprised a significant number of seedlings and saplings. This is the most expansive species of the studied regenerations. It is able to establish compact, dense regeneration stands, exceeding the share of birch in the older sapling stage. Biocenotic species, such as rowan and goat willow *Salix caprea* L., are abundantly represented. Aspen *Populus tremula* L. is less represented in the regeneration, whereas the presence of such species as European

Table 2. Percentage of tree species in development phases, in study sites 1–3 and variants of experiment: 1 – 100% birch clear cut, 2 – 50% birch cut, 3 – no cuts

Site/ Variant	Seedlings	Younger saplings	Older saplings	Ingrowths
1/1	23 birch; 18 willow; 16 beech; 15 spruce; 14 rowan; 14 fir	40 birch; 27 spruce; 17 beech; 5 willow; 4 rowan; 3 fir; 3 aspen; 1 larch	54 birch; 42 spruce; 3 beech; 1 larch	100 spruce
2/1	38 spruce; 35 birch; 12 aspen; 9 beech; 4 willow; 1 fir; 1 cherry; 1 sycamore	56 spruce; 20 birch; 17 beech; 3 aspen; 3 willow; 1 rowan, pine	90 spruce; 7 beech; 2 birch; 1 willow, larch, rowan, aspen, pine	-
3/1	45 fir; 41 spruce; 7 birch; 7 beech	48 spruce; 27 birch; 14 fir; 9 rowan; 1 beech; 1 aspen	61 birch; 38 spruce; 1 rowan, beech, aspen	100 spruce
1/2	62 fir; 38 spruce	68 spruce; 20 birch; 7 fir; 5 beech	48 spruce; 45 birch; 7 beech	100 birch
3/2	47 fir; 40 spruce; 13 rowan	67 spruce; 22 fir; 8 birch; 3 rowan	59 spruce; 39 birch; 1 rowan; 1 fir, aspen	100 birch
1/3	35 spruce; 28 fir; 26 rowan; 5 aspen; 4 beech; 2 pine	43 spruce; 42 rowan; 10 beech; 4 birch; 1 willow	81 birch; 14 spruce; 3 beech; 1 rowan; 1 larch, fir, aspen	100 birch
2/3	57 spruce; 18 beech; 17 willow; 6 aspen; 2 birch	71 spruce; 24 beech; 2 rowan; 1 willow; 1 aspen; 1 birch	86 spruce; 7 birch; 4 beech; 2 willow, 1 larch, fir, pine	100 birch
3/3	44 fir; 44 spruce; 12 rowan	46 spruce; 25 fir; 10 aspen; 7 rowan; 5 birch; 3 larch; 2 beech; 2 willow	65 birch; 29 spruce; 2 aspen; 1 beech; 1 rowan; 1 larch; 1 fir, willow	100 birch

larch *Larix decidua* Mill. and Scots Pine *Pinus sylvestris* is scattered and insignificant.

In terms of the analysed sites and variants, the most numerous species of seedlings in most cases was spruce (Table 3). The plantings of fir located at the lowest elevation attained comparable numbers, while beech was less numerous. The birch sprouts located at the lowest elevation competed in numbers with the remaining species in the clear-cut variant. Seedlings of biocenotic species were locally numerous: rowan, willow, and aspen.

Expansive spruce regeneration was also quite numerous in the younger sapling phase (Table 4). Their average number per 1 ha reached 5850 trees (study site 2, variant 3). Spruce competed with other target species (fir, beech), which were less numerous. Younger birch saplings were the most numerous in the clear-cut variant, significantly exceeding the number of spruce saplings in the study site 1. Spruce continued to dominate over birch sprouts in the regeneration development phase under discussion in the other two study sites. The same was true for partial cuts and no cuts. Within the scope of the analysed study sites and variants, biocenotic species were locally numerous in the younger sapling and seedling phases.

In the first and third study sites (variant 1), the older sapling phase had more numerous birches than spruce (Table 5). Only in the second study site, where the number of overly dense older spruce saplings reached 10,858 stems/ha, the mutual relationship between the numbers of these species was reversed. Within the scope of the analysed study sites and variants, the disproportion between the large number of spruces and the small number of beech and fir trees was significantly higher in the phase under discussion than in the remaining phases of the regeneration process. Also, biocenotic species were much less represented.

Few trees in the analysed study sites and variants attained the parameters of ingrowth phase, which begins the construction of the highest tree layer (Table 6). In the variant of birch clear-cuts in study sites 1 and 3, the ingrowth phase was represented by single spruces. Spruce ingrowth did not occur in the analogous variant of the second study site, where the trees in overly dense regeneration did not reach such a size. In the case of other analysed variants, ingrowth was formed by birch, which was also not very numerous at this stage of development.

After a period of two or even three years after clear cutting in the first experimental variant, the average DBH of birch sprouts was smaller than the average DBH of those target species exceeding 1.3 m in height (Table 7). The remaining regeneration species also had small DBHs.

In the second and third variants, where the birches were partially cut or not cut, the DBH of this species reached 13.5 cm. Other species were characterized by much smaller DBHs, with a maximum of 6.5 cm.

After 2-3 years, birches in the areas that were clear cut (variant 1) began competing in terms of height with the regeneration of other species (Table 8). Due to the intensive growth increases of the birch sprouts, their average height

Table 3. Average number of seedlings by species per hectare, in study sites 1–3 and variants of experiment: 1 – 100% birch clear cut, 2 – 50% birch cut, 3 – no cuts

Site/ Variant	Birch	Spruce	Beech	Fir	Willow	Rowan	Aspen	Pine	Cherry	Sycamore
1/1	767	483	533	467	600	467	-	-	-	-
2/1	2266	2488	622	89	222	-	755	-	44	44
3/1	267	1466	267	1600	-	-	-	-	-	-
1/2	-	1066	-	1733	-	-	-	-	-	-
3/2	-	800	-	933	-	267	-	-	-	-
1/3	-	1266	133	1000	-	933	200	67	-	-
2/3	67	2066	667	-	600	-	200	-	-	-
3/3	-	1066	-	1066	-	267	-	-	-	-

Table 4. Average number of younger saplings by species per hectare, in study sites 1–3 and variants of experiment: 1 – 100% birch clear cut, 2 – 50% birch cut, 3 – no cuts

Site/ Variant	Birch	Spruce	Beech	Fir	Willow	Rowan	Aspen	Larch	Pine
1/1	2050	1350	850	150	250	200	150	50	-
2/1	2100	5800	1800	-	267	67	333	-	33
3/1	2300	4200	100	1200	-	800	100	-	-
1/2	800	2800	200	300	-	-	-	-	-
3/2	500	4300	-	1400	-	200	-	-	-
1/3	350	3750	900	-	50	3650	-	-	-
2/3	50	5850	1950	-	100	300	100	-	-
3/3	300	2700	100	1500	100	400	600	200	-

Table 5. Average number of older saplings by species per hectare, in study sites 1–3 and variants of experiment: 1 – 100% birch clear cut, 2 – 50% birch cut, 3 – no cuts

Site/ Variant	Birch	Spruce	Beech	Fir	Willow	Rowan	Aspen	Larch	Pine
1/1	5 200	4 025	350	-	-	-	-	75	-
2/1	208	10 858	808	-	58	8	17	17	17
3/1	8 550	5 300	75	-	-	150	25	-	-
1/2	3 400	3 600	525	-	-	-	-	25	-
3/2	3 325	5 100	-	75	-	100	25	-	-
1/3	7 713	1 388	300	25	-	75	13	50	-
2/3	1 050	12 150	625	25	200	-	-	38	13
3/3	4 550	2 000	100	50	25	100	150	50	-

Table 6. Average number of ingrowths by species per hectare, in study sites 1–3 and variants of experiment: 1 – 100% birch clear cut, 2 – 50% birch cut, 3 – no cuts

Site/Variant	Birch	Spruce
1/1	-	100
2/1	-	-
3/1	-	50
1/2	750	-
3/2	350	-
1/3	475	-
2/3	300	-
3/3	325	-

surpassed at times (study site 3) the average height of the spruce regeneration. Birch sprouts had the lowest height where the very dense spruce regeneration hindered their growth (study site 2). Spruce dominated the other species accompanying the birch at all study sites.

In the second and third variants, where the birches were partially cut or not cut, the tallest birches reached a height of about 9 m, decisively dominating the remaining tree species. Most of the spruces in these experimental variants were higher than the remaining species accompanying the birches. Exceptions to this were single specimens of larches and aspens.

3.2. Dynamics of the number of birches following cuts

Clear-cutting birch regeneration in the research plots resulted in the growth of stump sprouts. The dynamics of the number of birch regeneration not exceeding a DBH of 2 cm (and therefore, also of the stump sprouts) was expressed by comparing the results of its inventory at the beginning and end of the study period.

The growth of birch stump sprouts depends on the severity of cuts (Fig. 2). In the variant where all the birches were removed, the number of analysed regenerating trees within 2−3 years in all study sites even exceeded 10,000 per hectare, whereas initially, it had not exceeded 300 stems/ha.

Removing half of the initial number of birches (variant 2) did not cause such an extreme reaction. Even though a nearly threefold increase in numbers was noted compared to the initial state for this variant in the first study site, it was still a relatively small increase compared to the clear-cut variant. Partial cuts made in the third study site did not result in an increase in the number of analysed regeneration.

In the absence of cuts (variant 3), changes in the number of youngest developmental phases were small and resulted from dying of the weakest, shaded birch regeneration or by the regeneration having achieved higher DBH parameters (decrease in numbers – study sites 1 and 2). The emergence of new birch seedlings was sporadically observed (insignificantly increasing its numbers – study site 3). No sprout development was recorded.

Table 7. Range and average DBH (cm) of tree species in study sites 1–3 and variants of experiment: 1 – 100% birch clear cut, 2 – 50% birch cut, 3 – no cuts

Site/ Variant	Birch	Spruce	Beech	Fir	Willow	Rowan	Aspen	Larch	Pine
1/1	0.8 (0.5–4.5)	2.6 (0.5–9.5)	1.1 (0.5–3.5)	-	-	-	-	0.8 (0.5–1.5)	-
2/1	0.9 (0.5–3.5)	1.7 (0.5–5.5)	1.0 (0.5–5.5)	-	0.8 (0.5–2.5)	0.5 (0.5–0.5)	0.5 (0.5–0.5)	2.5 (0.5–3.5)	0.5 (0.5–0.5)
3/1	0.7 (0.5–1.5)	2.2 (0.5–8.5)	2.8 (0.5–5.5)	-	-	0.8 (0.5–1.5)	1.5 (1.5–1.5)	-	-
1/2	4.9 (0.5–13.5)	1.4 (0.5–4.5)	1.4 (0.5–3.5)	-	-	-	-	6.5 (6.5–6.5)	-
3/2	4.0 (0.5–10.5)	1.5 (0.5–5.5)	-	0.8 (0.5–1.5)	-	0.8 (0.5–1.5)	0.5 (0.5–0.5)	-	-
1/3	3.1 (0.5–13.5)	1.1 (0.5–3.5)	0.9 (0.5–3.5)	1.0 (0.5–1.5)	-	0.8 (0.5–2.5)	5.5 (5.5–5.5)	2.0 (1.5–2.5)	
2/3	5.1 (0.5–10.5)	1.7 (0.5–6.5)	1.0 (0.5–4.5)	1.5 (0.5–2.5)	0.7 (0.5–2.5)	-	-	2.2 (1.5–3.5)	1.5 (1.5–1.5)
3/3	3.0 (0.5–11.5)	1.3 (0.5–4.5)	0.5 (0.5–0.5)	1.5 (1.5–1.5)	0.5 (0.5–0.5)	1.5 (0.5–3.5)	1.3 (0.5–1.5)	2.5 (0.5–4.5)	-

3.3. Height increment of spruce regeneration

An important issue for regeneration while developing under the canopy of other species is the effect of shade on height increment. In study site 1, the three-year height increment of spruce was compared in the research plots differing by the severity of cuts in the birches forming a canopy above the spruce. The largest increase occurred in the plot where the birch forecrop was clear cut, whereas the smallest occurred where there was no cut (Fig. 3). The results of the Kruskal-Wallis test ($p = 0.0006$) showed that significant differences in spruce increment occurred between the plot where all the birches were cut and the area that was not cut at all. There was no significant difference in the height increment of spruce growing in the area where 50% of the birches were cut compared to the analogous increment in the other two variants.

In study site 2 (Fig. 4), only the two-year height increment of spruce regeneration in the extreme variants was compared: in the completely birch-free plot and in the plot with intact birch (there was no intermediate variant of 50% of birch cut at this site). The results differed from those of the first site. Spruce height increment in the clear-cut variant was significantly lower than that in the absence of cuts. The Kruskal-Wallis test ($p = 0.0276$) confirmed the significance of differences between these two variants.

In study site 3, the two-year height increment of natural spruce regeneration was compared using the same cut variants as in study site 1. The results differed from those obtained in study site 1. The largest increase occurred in the absence of cuts and the smallest – in the plot completely devoid of birch. However, the difference between the averages was minimal in this case, with very high variability of the studied feature (Fig. 5). The Kruskal-Wallis test ($p = 0.9454$) did not show that the differences in increment between the particular variants were significant.

4. Discussion

The previously insufficient recognition of the problem of dynamically developing birch regeneration in post-disaster areas of the Silesian Beskid Mountains (Ambroży 2010, Ambroży, Kosibowicz 2012) prompted the authors to present the obtained results, despite the shortcomings of the conducted

Table 8. Range and average height (m) of tree species in study sites 1–3 and variants of experiment: 1 – 100% birch clear cut, 2 – 50% birch cut, 3 – no cuts

Site/ Variant	Birch	Spruce	Beech	Fir	Willow	Rowan	Aspen	Larch	Pine	Cherry	Sycamore
1/1	1.72 (0.32–2.22)	2.24 (0.27–6.41)	0.90 (0.26–1.94)	0.40 (0.35–0.56)	0.48 (0.39–0.69)	0.71 (0.28–0.79)	0.90 (0.90–0.90)	2.33 (1.09–3.15)	-	-	-
2/1	0.63 (0.28–1.88)	1.61 (0.34–2.26)	1.15 (0.30–2.20)	0.30 (0.30–0.30)	0.74 (0.28–1.54)	0.88 (0.79–1.60)	0.43 (0.25–1.54)	2.76 (2.76–2.76)	0.98 (0.75–1.42)	0.48 (0.48–0.48)	0.21 (0.21–0.21)
3/1	1.94 (0.44–2.26)	1.67 (0.39–6.80)	0.88 (0.35–3.10)	0.49 (0.40–0.62)	-	1.00 (0.83–1.89)	1.00 (0.57–2.72)	-	-	-	-
1/2	5.39 (0.87–9.08)	1.53 (0.31–2.37)	1.93 (0.81–2.36)	0.36 (0.32–0.57)	-	-	-	6.51 (6.51–6.51)	-	-	-
3/2	4.30 (0.91–8.49)	1.81 (0.32–2.69)	-	0.63 (0.36–1.70)	-	0.69 (0.13–1.81)	1.71 (1.71–1.71)	-	-	-	-
1/3	5.08 (0.72–9.08)	1.03 (0.33–1.95)	1.03 (0.42–0.81)	0.32 (0.29–1.91)	0.56 (0.56–0.56)	0.70 (0.35–1.88)	0.82 (0.35–8.31)	3.02 (3.02–3.02)	0.27 (0.27–0.27)	-	-
2/3	4.37 (0.10–6.37)	2.12 (0.32–2.94)	0.96 (0.34–2.04)	1.96 (1.96–1.96)	0.62 (0.13–1.94)	0.76 (0.76–0.76)	0.50 (0.39–0.71)	3.93 (3.93–3.93)	1.97 (1.97–1.97)	-	-
3/3	4.55 (0.69–8.05)	1.39 (0.38–2.60)	1.15 (0.60–1.69)	0.59 (0.35–1.82)	0.83 (0.52–2.05)	0.92 (0.41–2.10)	1.02 (0.79–1.91)	1.46 (0.77–4.23)	-	-	-

field experiments. The main drawback was the low number of areas representing the second variant of partial cuts. This was due to the terrain conditions in the mountains, as well as to the considerable labour intensity of the performed treatments and measurements. However, presenting the results is also indicated by the fact that they may prove useful in developing methods for achieving the overriding purpose of undertaking economic activities in post-disaster areas. The aim is to achieve future tree stands that have much greater stability and resistance to stress compared to the spruce that died, primarily by shaping their appropriate species composition, structure and spatial structure (Matička 2000; Šach et al. 2000; Vacek, Balcar 2000; Szabla 2004; Kantor 2004).

The study confirmed earlier findings in this area on the quick sprouting of other species of trees, including biocenotic species and target species, under a birch canopy (Ambroży 2010). The study area has many biocenotic species under the birch canopy, such as rowan, goat willow, and aspen. They are eagerly grazed by game (Motta 2003; Kulla et al. 2009) and can therefore act as a buffer for the target species. This fact should be taken into account when conducting treatments to tend the stands.

The research conducted fully confirmed the high rate of height increment of the birches, both for the self-sown trees as well as for those growing as stump sprouts. Especially at a young age, this is generally significantly higher than the rate of height increment for most species coexisting with birches (Braathe 1988; Karlsson et al. 1997; Ceitel 1994; Ceitel, Iszkuło 2000; Zhukovskaya, Ulanova 2006; Ambroży 2010). In case of the first generation of self-sown, naturally regenerating birch, this is a positive phenomenon because it can fulfil its role as the canopy cover for the regeneration of other species. On the other hand, the very numerous and fast-growing stump sprouts formed after extensive cutting results in the birch taking over the space it occupies, competing with other species and suppressing them. This necessitates frequent interventions (not less often than every two years) of intermediate cuttings to remove sprouts. Moderate cuts (up to 50% of the number of birches) do not induce such a strong expansion of birch sprouts.

Moderate cuts that increase the lifespan of the remaining birches are also favoured in terms of their need to develop resistance to potential snow and glaze ice damage. In the investigated regeneration, reaching up to about 9 m in height, no damage has been observed

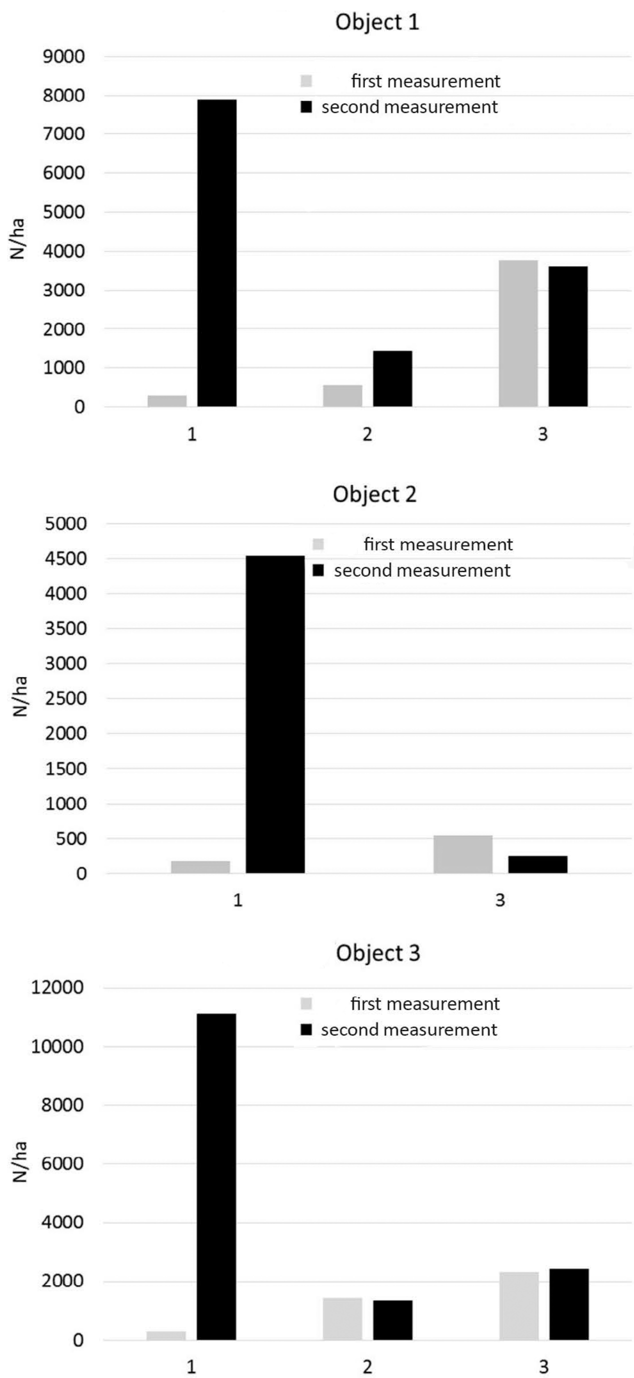

Figure 2. Changes in the number of birch regeneration not reaching DBH heights and with DBH less than 2 cm (object 1 – inventory repeated after three years, objects 2 and 3 – inventory repeated after two years): 1 – 100% of birch clear cut, 2 – 50% of birch cut, 3 – no cuts

to date due to atmospheric factors, as was declared by others (Łukaszewicz et al. 2010; Martiník, Mauer 2012). The latter authors mentioned that rich habitats of naturally regenerating birches in the highest altitude classes (8−15 m) were most intensively damaged by snow. The dominant type of damage to the trees, 67−95% of the total number, was bending. Breakage was observed in less than 4% of the trees. The results of the above-mentioned studies indicate that similar damage can be expected with the development of birch regeneration in the post-disaster areas of the Silesian Beskids.

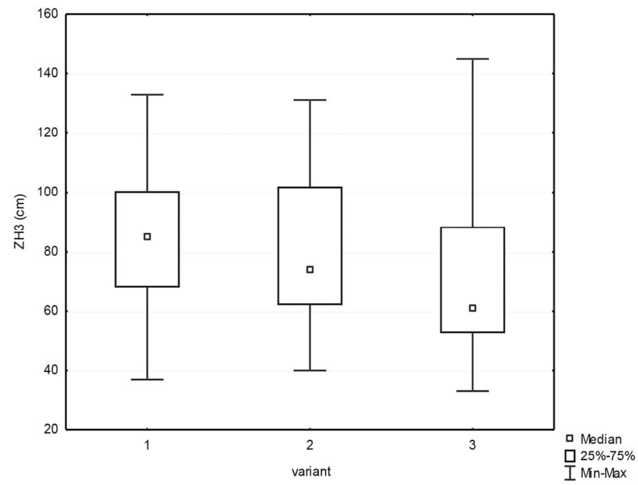

Figure 3. Three-year spruce height increment depending on the quantity of birch forecrop left in the study site 1: 1 – 100% of birch clear cut, 2 – 50% of birch cut, 3 – no cuts

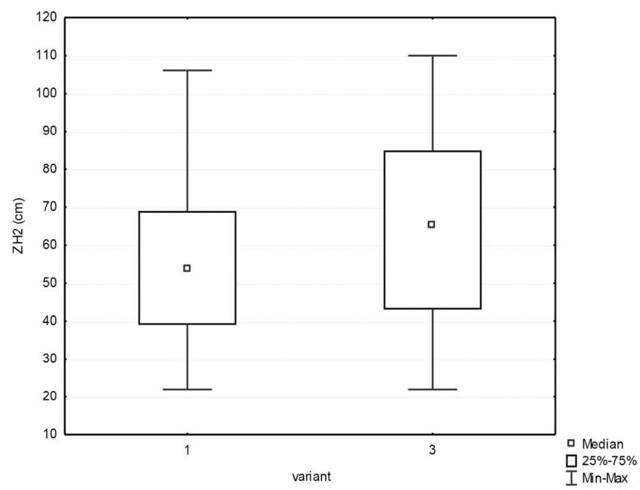

Figure 4. Two-year spruce height increment depending on the quantity of birch forecrop left in study site 2: 1 – 100% of birch clear cut, 3 – no cuts

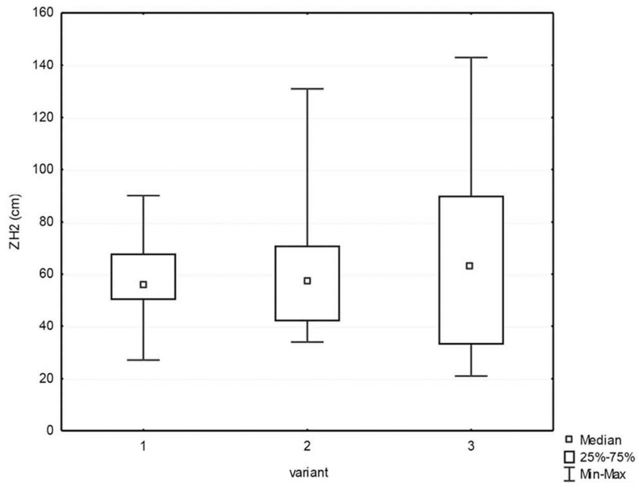

Figure 5. Two-year spruce height increment depending on the quantity of birch forecrop left in study site 3: 1 – 100% of birch clear cut, 2 – 50% of birch cut, 3 – no cuts

This study did not unequivocally indicate the effect of shading on the two-year height increment of spruce. In the case of third site, differences in the two-year height increment were not significant, while at the second site, they differed from what was expected − spruce height increment was significantly greater under the canopy. This indicates the likely dominance of some other factor affecting height increment than shading. In this case, it may be the overly dense spruce regeneration compared to the growth at other sites. High intra-species competition in open space causes the strong growth of a few individuals, limiting the growth of the remaining ones, which represent the vast majority. This is indicated by the low average two-year height increment in the recorded value range. The spruces under the birch canopy were growing at a slightly lower density, which does not cause such strong competition, and their height increments were more evenly distributed. This is evidenced by the value of the average two-year height increment, located approximately midway in the recorded range of values. In effect, this can cause significant differences in the height increment of overly dense spruce regeneration.

In turn, the three-year height increment of spruce at the first study site was significantly higher in the open space than under the birch canopy. Špulák et al. (2014) showed that only a very high density of this species' canopy may reduce the height increment of spruce to a certain degree. Its restriction to rich habitat does not have to be a disadvantage because significant growth increases the susceptibility of trees of this species to mechanical damage (Spiecker 2000). Spruce has higher light requirements compared to such target species as fir or beech (Jaworski 2011), so the risk of limiting the height increment of these species under a birch canopy is lower, and the results of other studies and the observations of practitioners justify the use of this cover (Ceitel, Iszkuło 2000; Ambroży 2010; Matl 2015). The beneficial effect of birch canopy on the increment of spruce regeneration as compared, for example, to the canopy of older spruces, was also observed by Laiho et al. (2014). Significant height increments of spruce under the canopy of birches causes damage in the form of top kill from the trees rubbing together. During our study, this phenomenon was observed sporadically on single spruces, which were the highest trees in the regeneration. This is a situation calling for moderate cuts in the uppermost layer of birch, primarily within the most developed regeneration under the canopy.

5. Conclusions

Biocenotic species, which can constitute a food base for wildlife, accompany birch in large numbers in the post-disaster areas of the Silesian Beskid Mountains. They can act as a buffer for target species. Their occurrence should be considered when tending tree stands, among other things, to regulate species composition.

The significant expansiveness of spruce regeneration makes it necessary to constantly control the numbers of this species when tending stands, both in terms of its relationship to other target species (to support fir and beech) and the need to improve the structure of overly dense spruce regeneration.

Cutting all the birches in a large area results in the rapid growth of stump sprouts, which particularly threatens the young regeneration of other species, resulting in the need to remove the sprouts at intervals not exceeding two years.

In order to limit the development of stump sprouts, moderate cuts in birch regeneration should be made and the number of cut birches in the treated area should not exceed 50% of the initial state. The cuts should be made first in those areas having the best developed regeneration of target species growing under the canopy, to avoid damage caused by the trees rubbing together.

The long-term height increment of spruces under a birch canopy can be significantly lower than the height increment achieved in open spaces. In rich habitats, spruces growing under the canopy may be more resistant to weather-related damage in the future.

Conflict of interest

The authors declare the lack of potential conflicts of interest.

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Authors' contribution

S.A. – concept of the article, field work, work on the results, writing the article; T.Z. – field work, statistical analysis, work on the results; M.K., E.Ch-Z., R.V. – field work.

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