

**Zeitschrift:** Schweizerische Zeitschrift für Forstwesen = Swiss forestry journal = Journal forestier suisse

**Herausgeber:** Schweizerischer Forstverein

**Band:** 156 (2005)

**Heft:** 12

**Artikel:** Beech sapling architecture following small and medium gap disturbances in silver fir-beech old-growth forests in Slovenia

**Autor:** Diaci, Jurij / Kozjek, Lahorka

**DOI:** <https://doi.org/10.5169/seals-1098084>

### **Nutzungsbedingungen**

Die ETH-Bibliothek ist die Anbieterin der digitalisierten Zeitschriften auf E-Periodica. Sie besitzt keine Urheberrechte an den Zeitschriften und ist nicht verantwortlich für deren Inhalte. Die Rechte liegen in der Regel bei den Herausgebern beziehungsweise den externen Rechteinhabern. Das Veröffentlichen von Bildern in Print- und Online-Publikationen sowie auf Social Media-Kanälen oder Webseiten ist nur mit vorheriger Genehmigung der Rechteinhaber erlaubt. [Mehr erfahren](#)

### **Conditions d'utilisation**

L'ETH Library est le fournisseur des revues numérisées. Elle ne détient aucun droit d'auteur sur les revues et n'est pas responsable de leur contenu. En règle générale, les droits sont détenus par les éditeurs ou les détenteurs de droits externes. La reproduction d'images dans des publications imprimées ou en ligne ainsi que sur des canaux de médias sociaux ou des sites web n'est autorisée qu'avec l'accord préalable des détenteurs des droits. [En savoir plus](#)

### **Terms of use**

The ETH Library is the provider of the digitised journals. It does not own any copyrights to the journals and is not responsible for their content. The rights usually lie with the publishers or the external rights holders. Publishing images in print and online publications, as well as on social media channels or websites, is only permitted with the prior consent of the rights holders. [Find out more](#)

**Download PDF:** 01.05.2026

**ETH-Bibliothek Zürich, E-Periodica, <https://www.e-periodica.ch>**

# Beech sapling architecture following small and medium gap disturbances in silver fir-beech old-growth forests in Slovenia

JURIJ DIACI and LAHORKA KOZJEK

**Keywords:** Beech; silver fir; old-growth forest; canopy shading; gaps; tree architecture. FDK 231 : 421.1 : (497.12)

## 1. Introduction

Common beech (*Fagus sylvatica* L.) is the key species of European temperate forests, but past anthropogenic practices, including clearing, grazing, and silviculture, tended to favour conifers (silver fir, spruce, pines) and shade-intolerant broadleaves (oaks and maples), so the current range of beech is significantly smaller. However, it is gaining importance in contemporary silviculture for a variety of reasons. Many of these reasons are linked to the advancement of nature based forest management practices, which are based on knowledge of site ecology and natural processes (LEIBUNDGUT 1949, MLINŠEK 1976, SCHÜTZ 1999). Moreover, as conifer plantations become increasingly degraded, beech can play an important role as an ameliorative species (DIACI 2002). The economic value of beech timber has also significantly increased. As a consequence, maintaining stable beech forest ecosystems is of great concern in the face of global climate change.

Beech forests are managed with a variety of silvicultural systems, from coppicing and clear-cut management with planting to selection management (SCHÜTZ 2001a). Currently, the most widespread system for management of beech forests is the regular shelterwood system (BURSCHEL & HUSS 1997, MATTHEWS 1999). Generally, it yields appropriate natural regeneration and wood of high commercial quality. Most of the existing beech stands in European countries originate from the application of large-scale shelterwood management systems over the past two centuries. In contrast to natural forests, the structure and dynamics of these stands often have minimal variation in tree dimensions and age, uniform structures, disturbed regeneration cycles, and lead to high costs for the tending of young stands. For all these reasons, there are recent trends towards decreasing the regeneration and thinning costs and maintaining structural and species diversity, while at the same time producing high quality timber.

This can be achieved with alternative systems, such as single and group selection, irregular shelterwood, and diameter harvests. These systems more closely resemble natural disturbance processes and require less tending and pre-commercial thinning, but the expected commercial quality may be lower (SAFAR 1964, BRINAR 1969, SCHÜTZ 2001a). The lower commercial quality is mainly due to a higher proportion of read heart, especially when working with long production periods, as well as to the inferior commercial architecture of adult trees when compared to systems regenerating on larger scales. The development of tree architecture is especially interesting in the context of the regeneration cycle. Beech is a species with weak epinastic control (SCHÜTZ 1992), which gives rise to several problems and limitations when introducing small-scale regeneration practices or selection systems in beech forest. These include intensive lateral growth and smaller volume production per unit of growth space compared to conifers (SCHÜTZ 2001a, 2001b). Beech saplings growing individually, i.e. not in groups, result in the development of large crowns, activation of epicormic shoots, and numerous and thicker branches. The effects of heavy shading on beech saplings include plagiotropic growth, forked and broom-shaped growth of terminal

shoots, sabre, knee-shaped or plagiotropic main stems, and reduced height and volume growth of stems, leaves, and buds (SAFAR 1964, BRINAR 1969, SCHÜTZ 1992, SAGHEB-TALEBI 1996). All of these issues influence the future commercial quality of trees (SCHÜTZ 2001b).

In silver fir-beech, old-growth forest in Slovenia, beech regeneration predominantly develops in small and medium gaps resulting from endogenous and exogenous disturbance (mostly wind) (ZEIBIG *et al.* 2005). The light levels in gaps, even in openings of similar size, are lower compared to gaps in nature-based managed forest due to taller trees, non-thinned stands at gap edges, presence of coarse woody debris, development of uneven advanced regeneration, and the absence of transportation systems (DIACI *et al.* 2005). In spite of prevalent low light levels during the regeneration cycle and presence of plagiotropic trees in the regeneration, adult beech trees with predominantly straight stems and desirable architecture were often observed and described (MLINŠEK 1967, ROZENBERGAR & DIACI 2003). Therefore, we posed the following research questions: 1) do different disturbance regimes result in different beech sapling architecture (endogenous, small-scale baseline mortality processes versus exogenous, medium-scale disturbance caused by windstorm, respectively), and 2) under which gap size (light environment) a significant increase in plagiotropic saplings can be found. Given that taller, more dominant regeneration is most likely to reach the canopy, our study focused on beech saplings between 3.8–8 m high.

## 2. Materials and methods

The research gaps were selected in the old-growth forests of Pecka (45,75°N, 14,99°E, 800–910 m elevation, 60.2 ha) and Rajhenav (45,66°N, 15,01°E, 850–920 m, 51.1 ha). Both are located in the Dinaric region of southern Slovenia. The average annual temperature varies between 6 °C and 8 °C and precipitation from 2000 to 2500 mm. Precipitation is equally distributed over the year, resulting in permanent air and soil humidity. Soils are calcambisol with variable depth, and issue from underlying bedrock of limestone and pockets of dolomite. The relief is heterogeneous, interwoven with sinkholes and other karst characteristics. The vegetation was classified as beech-silver fir forest (*Omphalodo-Fagetum*) according to the Braun-Blanquet school (PUNCER 1980, MARINČEK *et al.* 1992). The Pecka reserve is dominated by beech (81%) and fir (*Abies alba* Mill.) (19%) with the occasional occurrence of other species, including spruce (*Picea abies* (L.) Karsten), maple (*Acer pseudoplatanus* L.), and elm (*Ulmus glabra* Huds.). Due to significant silver fir decline, the overall growing stock has declined over the past 40 years from 942 m<sup>3</sup>/ha to 714 m<sup>3</sup>/ha (ROZENBERGAR 2000). The growing stock in Rajhenav over the same period has remained nearly constant (800 m<sup>3</sup>/ha). Here, the share of silver fir first increased from 27% in 1893 to 64% in 1967 and then steadily decreased to 57% in 1995 (HARTMAN 1987).

In the Pecka reserve, a windstorm event in 1983 blew down over 300 canopy trees in approximately 12 ha of the forest, which created many messy, irregular shaped, interconnected

gaps over a broad range of size classes (TURK *et al.* 1985, NAGEL & DIACI 2005). For this research we selected a windthrow gap (henceforth «large gap») with no solitary trees in the gap interior and with saplings ranging from 4 to 8 m. The majority of saplings within the gap developed after the windthrow. For comparison, six small gaps were selected outside the windthrow area in Pecka and two small gaps were selected in the Rajhenav reserve, all of which had prevalent beech regeneration of comparable size (4 to 8 m). Further selection criteria for small gaps were the predominance of mature beech trees at gap edges, mainly because of strong lateral growth compared to silver fir, and absence of other gaps in the vicinity (non-overlapping gaps). The smaller gaps selected for study should therefore have much lower light levels than the windthrow gap.

In August 2003 we drew up a 1:200 scale map of all the gaps with the crown projections of gap edge trees (*figure 1*). Species, position, DBH, crown radii and height of the gap edge trees were recorded. The research plot was the expanded gap, defined by the imaginary lines connecting gap edge trees (*sensu* RUNKLE 1981). The canopy coverage of gaps was calculated as (extended gap size – gap size) / extended gap size.

For each sapling above 1.3 m tall, we measured the diameter at breast height (DBH) with a calliper ( $\pm 1$  mm) and the height with a measurement pole ( $\pm 1$  dm). For detailed analysis of tree architecture, we selected dominant saplings above 4 m tall, which were not overtopped and were evenly distributed in the gap. Saplings that were clearly established before the gaps formed were considerably taller than the regenera-

tion layer in the gaps, and were not sampled. For each dominant sapling the following characteristics were recorded: maximum crown width and crown width perpendicular to maximum width ( $\pm 1$  dm), intensity of stem bending – as maximum deviation of the stem from a straight line (cm/m in interval from 0.5 to 4.0 m), deviation of stem from vertical growth (cm/m in interval from 0.5 to 4.0 m), the height from the stem base to the first living branch ( $\pm 1$  cm), and the number of knots and healthy branches larger than 1/3 of DBH in the first 4 m of the stem. Dominant saplings were also scored for branching of the terminal shoot (straight, forked, broom-shaped) and damage (type and intensity in %). The slenderness was calculated as the height/DBH ratio of individual saplings. The crown area was calculated from the formula of an ellipse, using maximum crown width as the major axis and the perpendicular crown width as the minor axis. Crown asymmetry was calculated as the ratio of the two crown widths.

As the sapling height may influence many sapling characteristics, we employed an analysis of covariance (Ancova) to compare mean sapling characteristics between medium and small gaps with sapling height as a covariate. The relationship between the branching of terminal shoot and damage type and gap size was analysed with a Pearson Chi-square test. Using discriminant function analysis, we studied the possibility of discrimination between two populations of saplings from gaps of different sizes. We paid particular attention to finding the sapling characteristics that contribute most to the overall discrimination. All statistical analyses were conducted using Statistica version 6.0 (2001).

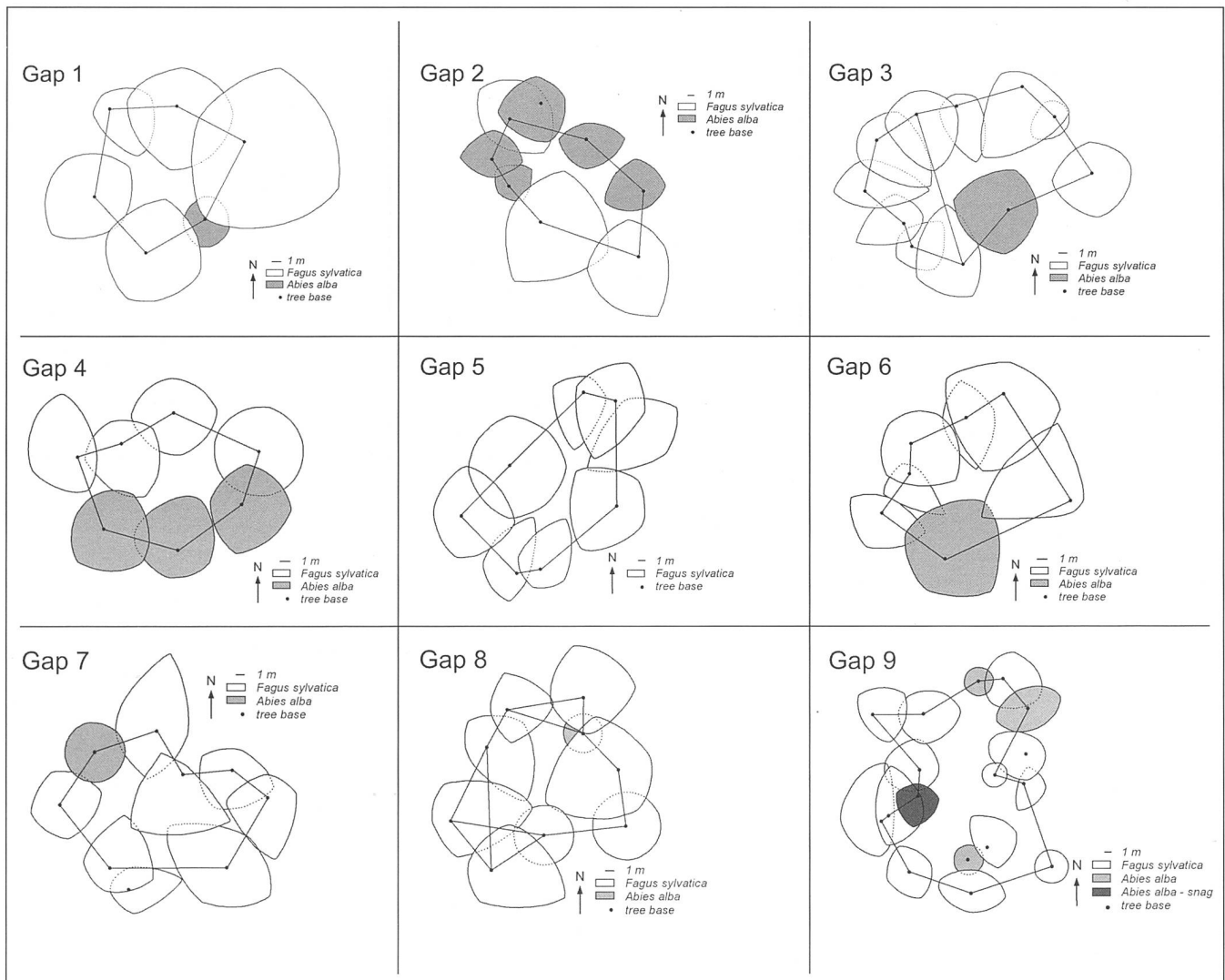


Figure 1: Ground plan of analysed gaps with crown projections of gap edge trees.

### 3. Results

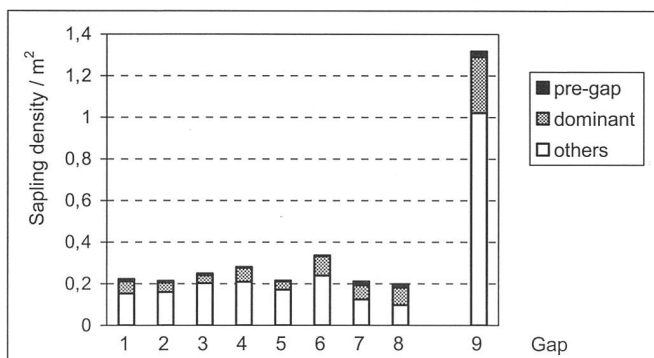
The size of small gaps ranged from 26 to 78 m<sup>2</sup>, while the larger, windthrow gap covered 352 m<sup>2</sup> (table 1). The size and mean canopy cover was similar among the small gaps, but differed from the large gap. Mean canopy cover was 80% in the small gaps, while the canopy cover of the large gap was 51%. This indicates significantly better light levels within large gap. The height and the species composition of gap edge trees for all the gaps were similar, with mostly mature beech trees (figure 1). Silver fir was more abundant in gaps 2 and 4. The trees surrounding the gaps had asymmetric crowns, suggesting gaps were closing from lateral growth of crowns (especially gaps 3, 4, 5, 6, 7, 8 on figure 1). Beech was by far the most prevalent species in the regeneration layer. Among 1469 saplings, we only found one elm, one spruce, and one advanced silver fir.

The overall mean density of saplings per m<sup>2</sup> was low, which is typical for old-growth forest (figure 2). The mean density of saplings in small gaps (0,23 individuals/m<sup>2</sup>) was 5.6 times lower than the large gap (1.30 individuals/m<sup>2</sup>). Nevertheless, the percentage of sapling categories was similar between gap

**Table 1: Gap location, size, and height of gap edge trees according to gap size (gaps 1–8 are small gaps and gap 9 is the large gap).**

Gap	EGS (m <sup>2</sup> )	GS (m <sup>2</sup> )	CC (%)	Hm (m)	Hmax (m)	Location
1	189	41	78	29,3	39,0	R
2	356	78	78	34,4	41,0	R
3	236	60	74	37,6	43,0	P
4	210	52	75	36,0	42,0	P
5	454	62	86	36,6	41,0	P
6	208	26	87	35,1	42,0	P
7	312	56	82	35,5	44,0	P
8	226	40	82	30,3	42,0	P
9	724	352	51	33,7	46,0	P

EGS expanded gap size      Hm      mean height of gap edge trees  
 GS gap size                      Hmax      maximum height of gap edge trees  
 CC canopy coverage              Location      R = Rajhenav and P = Pecka



**Figure 2: Mean sapling density in gaps according to pre-gap, dominant, and other sapling categories.**

**Table 2: Mean sapling DBH and height according to gap size (large, small) and sapling category.**

	DBH (mm)						Height (m)			
	N	Large gap	Small gap	N	Large gap	Small gap	Large gap	Small gap	Large gap	Small gap
Sapling category	N	Mean	SD	N	Mean	SD	Mean	SD	Mean	SD
Dominant	196	34	8,65	126	39	8,09	6,1	0,84	5,6	0,78
Others	739	13	5,94	367	16	8,60	3,2	1,05	2,5	0,84
Pre-gap	19	85	23,37	22	71	13,74	9,4	3,45	7,9	1,28

SD standard deviation

sizes, with 4% and 2% of advanced, pre-gap saplings and with 24.7% and 20.5% of dominant saplings in the small gaps and large gap, respectively. All saplings were significantly taller and thinner in the large gap compared to the small gaps, with the exception of the pre-gap saplings, which were taller and thicker in the medium gap (table 2).

#### Features of dominant saplings

The height of dominant saplings ranged between 3.8 and 8.0 m. Both extremes were found in the large gap. The dominant saplings were significantly taller and thinner in the large gap (table 3). The maximum DBH of dominant saplings (65 mm) was found in a small gap, while the minimum DBH (19 mm) was found in the large gap. The mean slenderness ratio was also higher in the large gap (186) than the small (145), and ranged from 84 in a small gap to a maximum of 275 in the medium gap. The mean crown area of dominant saplings in the large gap was nearly half (2.8 m<sup>2</sup>) that of the small gaps (5.9 m<sup>2</sup>). Moreover, the crowns were significantly shorter in the large gap compared to the small gaps, with 3.6 m and 4.3 m, respectively. The crown asymmetry was comparable between both gap sizes. The mean intensity of stem bending was higher in small gaps (3.6 cm/m) than in medium gaps (1.1 cm/m). The same was true for the deviation from vertical axis, with 12.9 cm/m compared to 6.4 cm/m in the small gaps and large gap, respectively. The mean stem height to the first branch was higher in the large gap (253 cm) than the small (125 cm), while the mean number of branches thicker than 1/3 of DBH was higher in small gaps (3.8 branches/4 m) than in the large gap (2.7 branches/4 m). The same was true for the mean number of knots thicker than 1/3 of DBH, with 1.4 knots/4 m and 0.6 knots/4 m in the small and large gap, respectively.

We found a significant relationship between branching of the terminal shoot and gap size ( $\chi^2 = 54$ , d.f. = 2,  $p < 0,001$ ), with more straight shoots in dominant saplings of the large gap (table 4). Broom-shaped saplings were found only in small gaps. A significant relationship was also found between the type of damage and gap size (table 4). Less damaged dominant saplings were found in the large gap (89%) compared to small gaps (73%). In small gaps there was a greater impact of wildlife, probably due to the lower density of saplings, while other mechanical damage, especially from fallen logs, was comparable.

The major features that allow us to discriminate between saplings growing in different sized gaps are the crown area with partial Wilks' Lambda of 0,84, followed by the stem height to the first branch, intensity of stem bending, and slenderness (table 5). The variable DBH was not included in the model because of the high relationship with other variables ( $R^2 = 0,95$ ) and low discrimination power. The discriminant function is best explained by the variables slenderness and height to the first branch, which both have positive signs, followed by the crown area and intensity of stem bending, both with negative signs.

**Table 3: Analysis of covariance results for the effect of gap size (large, small) on measured sapling characteristics.**

The covariate in the design was sapling height. Original and adjusted means after including the covariate in the model are given.

Sapling features		Large gap	Small gap	R <sup>2</sup>	F	p
		Mean	Mean			
DBH (mm)	original	34,2	39,5	0,52	171,81	0,000
	adjusted	32,3	41,4			
Slenderness (height/DBH)	original	186,1	144,8	0,34	83,05	0,000
	adjusted	187,3	143,6			
Crown area (m <sup>2</sup> )	original	2,8	5,9	0,34	84,52	0,000
	adjusted	2,5	6,1			
Crown length (m)	original	3,6	4,3	0,36	91,18	0,000
	adjusted	3,4	4,5			
Crown asymmetry (%)	original	75,5	76,8	-0,01	0,25	0,777
	adjusted	75,6	76,8			
Intensity of stem bending (cm/m)	original	1,1	3,6	0,30	70,58	0,000
	adjusted	1,2	3,5			
Deviation from vertical axis (cm/m)	original	6,4	12,9	0,20	41,86	0,000
	adjusted	6,7	12,6			
Stem height to the first branch (cm)	original	253,4	125,5	0,34	85,30	0,000
	adjusted	245,8	133,1			
Number of branches (N/4 m)	original	2,7	3,8	0,22	45,44	0,000
	adjusted	2,9	3,5			
Number of knots (N/4 m)	original	1,4	0,6	0,10	18,67	0,000
	adjusted	1,4	0,5			

**Table 4: Comparison of dominant sapling.**

a) damage type and b) branching of terminal shoot according to gap size in percentage.

	a) Damage type				b) Branching of terminal shoot		
	N	No damage	Wildlife	Other	Straight	Forked	Broom-shaped
Small gaps (1–8)	126	73,0	20,6	6,4	49,2	50,0	0,8
Large gap (9)	196	88,8	2,6	8,7	86,7	13,3	0,0

**Table 5: Discriminant function analysis results and factor structure coefficients.**

Sapling features	Partial Wilks' Lambda	F	p	R <sup>2</sup>	Factor structure coefficients
Slenderness	0,931	22,94	0,000	0,31	0,514
Intensity of stem bending	0,922	26,15	0,000	0,11	-0,458
Crown area	0,843	57,78	0,000	0,25	-0,465
Deviation from vertical	0,941	19,42	0,000	0,16	-0,351
Stem height to the first branch	0,905	32,84	0,000	0,72	0,487
Crown length	0,958	13,68	0,000	0,66	-0,241
No. of branches	0,980	6,44	0,012	0,47	-0,208
Crown asymmetry	0,983	5,53	0,019	0,07	-0,028
Branching pattern	0,994	1,94	0,164	0,12	-0,328
No. of knots	0,994	1,88	0,171	0,09	0,242
DBH <sup>a)</sup>	1,000	0,00	0,997	0,95	-

a) not included in the model

## 4. Discussion

The mean size of small gaps reached 52 m<sup>2</sup> and represents one of the most frequent groups of gap sizes, typical for Dinaric silver-fir beech forest (KONECNIK & ZAPLOTNIK 2001, ZEIBIG *et al.* 2005). They represent endogenous regeneration cycles resulting from mortality of individual trees or small groups of trees. Upon gap formation, tree regeneration occurs in sparse light levels and competes with strong lateral growth of crowns in beech-dominated canopies. For this reason, gaps smaller than 26 m<sup>2</sup> with saplings from 4 to 8 m tall do not occur in either of the old-growth forests. Moreover, small gaps often overlap, and larger gaps are created from time to time; it is therefore unlikely that the prevalent regeneration pattern is based on intense competition, as is the case for our small gaps.

Besides site conditions and the genetic make-up of trees, the light climate is one of the most important factors affecting tree architecture (SAGHEB-TALEBI 1996). Furthermore, when comparing different research results, the light environment should be carefully examined. In our research the majority of saplings were taller than 5 m, which made the use of standard light measurement techniques difficult (DIACI & THORMANN 2002). For this reason, we utilized the light data sets from the NAT-MAN project in the Rajhenav old-growth forest, where light was measured at 1.3 m height in gaps ranging in size from 200 to 1200 m<sup>2</sup> (ROZENBERGAR & DIACI 2003). With linear regression (diffuse radiation (%) = 70.35 x gap size (ha) + 4,8735) based on the above-mentioned data set, we estimated the mean relative diffuse radiation in small gaps (ca. < 5%) and the large gap (ca. > 7%) in our analyses. Since the saplings

in our study were taller, the light intensity above them was probably even higher. On the other hand, the small gaps in our study were non-overlapping, and we could therefore expect lower light levels than those estimated.

The overall mean density of saplings per m<sup>2</sup> was low, with an increasing trend towards higher light levels. This was in agreement with the results from BITORAJC & TANKO (2004), who analyzed beech saplings in height intervals from 3.0 to 5.5 m in sub mountain beech managed forest (*Hedero-Fagetum*). Also, MLINŠEK (1967) found 8 to 14 times more saplings in managed forest on a comparable site than in the old-growth forest of Pecka. In contrast, SAGHEB-TALEBI (1996) analyzed beech saplings in size interval from 1.0 to 1.7 m and found no relationship between saplings density and relative diffuse light levels.

When analyzing selected architectural characteristics of dominant saplings we found significant differences between the populations of the large gap (size 352 m<sup>2</sup>, estimated relative diffuse light > 7%) and small gaps (average size 50 m<sup>2</sup>, estimated relative diffuse light < 5%). In the large gap, an enhanced light environment influenced smaller deviations from vertical growth, lower intensity of stem bending, less thick (> 1/3 DBH) branches, longer stem length without branches, higher percentage of straight terminal shoots, and lower percentage of damages (especially from deer browsing) in dominant saplings. However, the slenderness (h/DBH ratio) was higher compared to small gaps, and sapling stability was therefore lower. Similar results regarding quality characteristics of saplings were found in managed forests for deviations from vertical growth, intensity of stem bending, and density of thick branches (> 1/3 DBH) (BITORAJC & TANKO 2004). These authors reported an improvement in these architectural characteristics with increasing radiation, while other features, such as height/DBH ratio and number of knots, showed no linear relationship. We supplemented the data from BITORAJC & TANKO (2004), who were working mostly in a light interval from 14–80%, with data from this study (low light levels). From this comparison it can be noted that many of the characteristics were not in a linear relationship with light intensity (figure 3). In addition, some characteristics had a negative relationship to light intensity. For example, maximum percentage of straight terminal shoots seems to be connected with minimal stability of saplings (expressed in h/DBH ratio). BITORAJC & TANKO (2004) found a negative influence of both light extremes on sapling quality and therefore proposed low to mid-range light intensity as optimal for regeneration (14–32% diffuse light or gap size from 100 do 1400 m<sup>2</sup>). SAGHEB-

TALEBI (1996) also found the light conditions below 20% and above 60–70% as negative for the quality of beech saplings.

## 5. Conclusions and implications for silviculture

We had difficulty locating 8 small non-overlapping gaps of about 50 m<sup>2</sup> in size with beech saplings taller than 4 m, although newly created gaps of this size are frequent in Dinaric silver fir-beech forest. It is likely that they do not represent the dominant process driving regeneration. Nevertheless, within these small gaps, beech sapling a-vertical, plagiotropic growth is favoured. In successive developmental phases, plagiotropic trees often die away because of lack of light. In the case of gap extension and additional light resources, they are regularly out-stripped by trees with straight stems that have the ability to accelerate height growth. Adult beech trees with growth irregularities in Dinaric silver fir-beech old-growth forests are often a sign of a sudden change in light levels due to intermediate to large-scale disturbances or anthropogenic influence.

The evaluation of our results in relation to beech forest management indicates that a depleted light environment, which would favour a high percentage of plagiotropic saplings during the normal regeneration period within an irregular shelterwood system, is unlikely. First regeneration cuts in formerly relatively closed stands may be an exception to this. This also indicates that appropriate sapling quality could be achieved within small-scale systems. However, if stands are not regenerated continuously and left for long periods of non-intervention after initiation of regeneration, which are then interrupted by felling or natural disturbance, shaded saplings are released abruptly and develop poor architectural characteristics (OLIVER & LARSON 1990).

### Summary

The objective of our research was to examine the effect of canopy shading on beech sapling architecture in the old-growth silver fir-beech forests of Pecka and Rajhenavski Rog. In August 2003 we sampled one plot (352 m<sup>2</sup>) in a large gap in Pecka, which was a result of a strong windstorm in 1983, and eight small gaps (26–78 m<sup>2</sup>) with similar sapling heights (3.8–8 m). A ground view of each gap was drawn including the characteristics of gap border trees and the density of separate sapling layers was recorded. The height and diameter were measured for each sapling, as well as the following quality characteristics on selected dominant saplings: width of the crown, number of larger branches and knots (>1/3 DBH), intensity of stem bending, deviation from vertical growth, number of terminal shoots, and the type of damage. The results show a negative effect of high canopy shading (estimated relative light intensity was below 5%) on the architectural quality of saplings. A lower overall density of saplings, greater intensity of bending and deviation from vertical growth, a shorter stem length without branches, a larger number of saplings with two terminal shoots, and a larger number of damaged saplings were observed in small gaps.

### Zusammenfassung

Architektur von jungen Buchen nach kleinen und mittleren Störungen in Tannen-Buchen-Urwäldern in Slowenien

Ziel der Untersuchung war es, den Einfluss der Überschirmung auf die Architektur von Buchen im Dickungsstadium in den Tannen-Buchen-Urwäldern Pecka und Rajhenavski Rog zu ana-

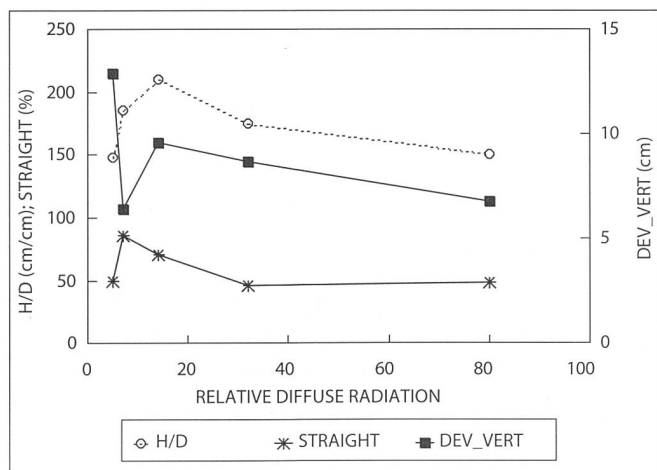


Figure 3: Relation between relative diffuse light and selected sapling quality features.

H/D = height/DBH ratio, DEV\_VERT = deviation of the stem from vertical axis, STRAIGHT = percentage of straight terminal shoots. Data was partially taken from BITORAJC & TANKO (2004).

lysieren. Untersuchungsobjekte waren im August 2003 eine grosse Lücke (352 m<sup>2</sup>) in Pecka, die 1983 durch einen Sturm entstanden war, und acht kleinere Lücken (26 bis 78 m<sup>2</sup>) mit vergleichbarer Dichtungshöhe (3,8 bis 8 m). In jeder Lücke wurde die Kronenprojektion der Randbäume gezeichnet und die Stammzahl-Dichte der verschiedenen Schichten der Dichtung aufgenommen. Bei jedem Buchenindividuum wurden die Höhe und der Durchmesser gemessen, bei den vorherrschenden Individuen auch die Kronenabmessung, Stammkrümmung und die Abweichung vom lotrechten Wuchs. Weiter wurden die dickeren Äste und Knoten (>1/3 BHD) gezählt und der Verzweigungstyp des Terminaltriebs sowie die Art von Schädigungen beurteilt. Die Resultate zeigen eine negative Wirkung starker Überschildung (relative Lichtstärke unter 5%) auf die Qualitätsmerkmale der jungen Buchen. In den kleinen Lücken wurden eine tiefere Individuendichte, grössere Stammkrümmung und Abweichung vom lotrechten Wuchs, kürzere astfreie Stammabschnitte sowie ein höherer Anteil Zwiesel und geschädigter Individuen festgestellt.

## Résumé

### Architecture de jeunes hêtres après des perturbations de petite et moyenne importance dans des forêts primaires de hêtraie à sapin en Slovénie

L'objectif de l'étude consistait à analyser l'influence du recouvrement sur l'architecture de jeunes hêtres, au stade du fourré, dans les massifs primaires de hêtraie à sapin de Pecka et Rajhenavski Rog. Les objets étudiés concernaient, en août 2003, une grande trouée (352 m<sup>2</sup>) à Pecka, causée par une tempête en 1983 et huit petites trouées (26 à 78 m<sup>2</sup>) dont les arbres avaient une hauteur comparable (3,8 à 8 m). Dans chaque surface, la projection des couronnes des arbres de lisière et la densité des tiges des diverses strates du fourré ont été relevées. La hauteur et le diamètre de chaque tige, ainsi que les dimensions de la couronne, la courbure du tronc et l'écart par rapport à la croissance d'aplomb des arbres prédominants ont été mesurés. De plus, l'étude a permis de dénombrer les branches et les nœuds d'un grand diamètre (>1/3 DHP) et d'évaluer le type de ramification de la pousse terminale ainsi que le genre de dégâts. Les résultats montrent l'effet négatif d'un recouvrement important (luminosité relative inférieure à 5%) sur les caractéristiques qualitatives des jeunes hêtres. Dans les petites trouées, on a constaté une densité réduite, une courbure accrue du tronc, un écart plus grand par rapport à la croissance d'aplomb, de plus courtes sections de tronc dépourvues de branches ainsi qu'une proportion plus élevée de fourches et d'individus endommagés.

Traduction: CLAUDE GASSMANN

## References

- ANONYMOUS 2001: Statistica, version 6.0. StatSoft, Inc., Tulsa, OK.
- BITORAJC, Z.; TANKO, B. 2004: Light effects on beech saplings architecture in submontane beech forests. Graduation thesis, University in Ljubljana, 83 p. (In Slovene with English summary.)
- BRINAR, M. 1969: Vpliv svetlobe na razvoj bukovega mladja. Zbornik gozdarstva in lesarstva, 7: 61–144. (In Slovene with German summary.)
- BURSCHEL, P.; HUSS, J. 1997: Grundriss des Waldbaus: ein Leitfaden für Studium und Praxis. Parey Buchverlag, Berlin, 487 p.
- DIACI, J. 2002: Regeneration dynamics in a Norway spruce plantation on a silver fir-beech forest site in the Slovenian Alps. For. Ecol. Manage. 161: 27–38.
- DIACI, J.; THORMANN, J.-J. 2002: A comparison of solar radiation estimation methods in natural beech forests in Slovenia from the point of view of regeneration ecology. Schweiz. Z. Forstwes. 153: 39–50. (In German with English summary.)
- DIACI, J.; ROZENBERGAR, D.; BONCINA, A. 2005: Interactions of light and regeneration in Slovenian Dinaric Alps: patterns in virgin and managed forests. In: Commarmot, B. (Ed.): Proceedings of the Conference «Natural Forests in the Temperate Zone of Europe – Values and Utilisation», Mukachevo, October 13–17, 2005. Birmensdorf, Swiss Federal Research Institute.
- HARTMAN, T. 1987: Pragozd Rajhenavski Rog. Strokovna in znanstvena dela, 89, BTF VTOZD za gozdarstvo, Ljubljana, 80 p. (In Slovene with German summary.)
- KONECNIK, K.; ZAPLOTNIK, V. 2001: Old-growth reserve Strmec. Graduation thesis, University in Ljubljana, 107 p. (In Slovene with English summary.)
- LEIBUNDGUT, H. 1949: Grundzüge der schweizerischen Waldbaulehre. Forstw. Cbl. 68, 5: 257–291.
- MARINČEK, L.; MUCINA, L.; ZUPANČIČ, M.; POLDINI, L.; DAKSKOBLER, I.; ACCETTO, M. 1992: Nomenklatorische Revision der illyrischen Buchenwälder (Verband *Aremonio-Fagion*). Studia Geobotanica 12: 121–135.
- MATTHEWS, J.D. 1999: Silvicultural systems. Clarendon Press, Oxford, 284 p.
- MLINŠEK, D. 1967: Pomlajevanje in nekatere razvojne značilnosti bukovega in jelovega mladovja v pragozdu na Rogu. Zbornik BF 15: 7–32. (In Slovene with German summary.)
- MLINŠEK, D. 1976: Die Naturverjüngung im Wirtschaftswald. Schweiz. Z. Forstwes. 127, 2: 81–90.
- NAGEL, T.A.; DIACI, J. 2005: Intermediate wind disturbance in an old-growth beech-fir forest in southeastern Slovenia. Submitted.
- OLIVER, C.D.; LARSON, B.C. 1990: Forest Stand Dynamics. McGraw-Hill, New York, 467 p.
- PUNCER, I. 1980: Dinarski jelovo-bukovi gozdovi na Kocevskem. Slovenska akademija znanosti in umetnosti, Ljubljana, 561 p. (In Slovene with German summary.)
- ROZENBERGAR, D. 2000: Stand dynamics of the virgin forest remnants of Pecka and Rajhenavski Rog. Gozd. vestn. 58, 3: 53–55. (In Slovene with English summary.)
- ROZENBERGAR, D.; DIACI, J. 2003 (eds.): Comparative studies of gap-phase regeneration in managed and natural beech forests in different parts of Europe: relations between tree regeneration, light and soil conditions, and ground vegetation, Part 7, Case study partner report, Slovenia. NAT-MAN Project Report (D 21), Biotechnical Faculty, Department for Forestry and Renewable Forest Resources, 37 S. – <http://www.flec.kvl.dk/natman>.
- RUNKLE, J.R. 1981: Gap regeneration in some old-growth forests of the eastern United States. Ecology 62, 4: 1041–1051.
- SAFAR, J. 1964: Kakvoća bukovega mladika u sastojinama Dinarskih planina. Sumarski list 88: 307–315. (In Croatian.)
- SAGHEB-TALEBI, K. 1996: Quantitative und qualitative Merkmale von Buchenjungwüchsen (*Fagus sylvatica* L.) unter dem Einfluss des Lichtes und anderer Standortsfaktoren. Beiheft zur Schweiz. Z. Forstwes. 78, 219 p.
- SCHÜTZ, J.-P. 1992: Die waldbaulichen Formen und die Grenzen der Plenterung mit Laubbaumarten. Schweiz. Z. Forstwes. 143: 442–460.
- SCHÜTZ, J.-P. 2001a: Der Plenterwald und weitere Formen strukturierter und gemischter Wälder. Parey Buchverlag, Berlin, 207 p.
- SCHÜTZ, J.-P. 2001b: Opportunities and strategies of transforming regular forests to irregular forests. For. Ecol. Manage. 151, 1–3: 87–94.
- SCHÜTZ, J.-P. 1999: Close-to-nature silviculture: is this concept compatible with species diversity? Forestry 72, 4: 359–366.
- TURK, V.; KASTELIČ, A.; HARTMAN, T. 1985: Gozdni rezervati Slovenije – Pragozd Pecka. Univerza v Ljubljani, Biotehniška fakulteta, Ljubljana, 75 S. (In Slovene with English summary.)
- ZEIBIG, A.; DIACI, J.; WAGNER, S. 2005: Gap disturbance patterns of a *Fagus sylvatica* virgin forest remnant in the mountain vegetation belt of Slovenia. For. Snow Landsc. Res. 79, 1/2: 69–80.

## Acknowledgements

The authors would like to thank Tom Nagel for valuable comments on the manuscript. This paper was inspired by a study stay at the ETH in Switzerland and is dedicated to my mentor Prof. Dr. Dr. h.c. Jean-Philippe Schütz.

## Authors

Prof. Dr. JURIJ DIACI, University of Ljubljana, Biotechnical Faculty, Department of Forestry and Renewable Forest Resources, Vecna pot 83, 1000 Ljubljana, Slovenia. E-mail: jurij.diaci@bf.uni-lj.si.  
LAHORKA KOZJEK, dipl. Forsting., Turnse 3, 1233 Dob pri Domzalah, Slovenia.