

Article

Plant Species Turnover on Forest Gaps after Natural Disturbances in the Dinaric Fir Beech Forests (*Omphalodo-Fagetum sylvaticae*)

Blanka Ravnjak ^{1,*}, Jože Bavcon ¹ and Andraž Čarni ² ¹ Biotechnical Faculty, University Botanic Gardens Ljubljana, 1000 Ljubljana, Slovenia; joze.bavcon@bf.uni-lj.si² Research Centre of the Slovenian Academy of Science and Arts, Jovan Hadži Institute of Biology, 1000 Ljubljana, Slovenia; carni@zrc-sazu.si

* Correspondence: blanka.ravnjak@bf.uni-lj.si; Tel.: +386-31336507

Abstract: We studied species turnover and changes of ecological conditions and plant strategies on forest gaps created by natural disturbances (sleet, windthrow). We studied five forest gaps and a control plot within in the Dinaric silver fir-beech forest in the southern part of Slovenia. Forest gaps varied in age and size. The total number of recorded species in gaps was 184, with the highest number (106) at the largest forest gap and with the 58 species at the control locality in a juvenile beech forest. Forest gaps were predominantly colonised mostly by species of understory, forest margins, and forest clearings. The species presented in all forest gaps are representatives of the understory of beech forests. Species colonising forest gaps prefer habitats with more sunlight, medium wet to dry soil, and are tolerant to high daily and seasonal temperature fluctuations. In gaps, the community of plant species has a competitive strategy, which is also complemented with a stress-tolerator strategy. We determined that a forest gap represents a significant habitat patch, especially for those plant species which were not present there before.



Citation: Ravnjak, B.; Bavcon, J.; Čarni, A. Plant Species Turnover on Forest Gaps after Natural Disturbances in the Dinaric Fir Beech Forests (*Omphalodo-Fagetum sylvaticae*). *Diversity* **2022**, *14*, 209. <https://doi.org/10.3390/d14030209>

Academic Editors: Lucian Dinca, Miglena Zhiyanski and Michael Wink

Received: 15 February 2022

Accepted: 8 March 2022

Published: 11 March 2022

Publisher's Note: MDPI stays neutral with regard to jurisdictional claims in published maps and institutional affiliations.



Copyright: © 2022 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

Keywords: forest gaps; plant colonisation; community strategy; Dinaric fir-beech forests; Ellenberg values

1. Introduction

Forest gaps are areas in a forest stand that have been created by the death of individual or multiple trees [1]. Forest gaps are part of forests and a typical stage of forest dynamics [2]. Every newly formatted gap results in changes to certain environmental factors, also affecting the flora and fauna. The created forest gaps can vary in size and shape. Depending on the size and gap shape, there are also changes in environmental factors [3]. When a forest gap forms, the light availability and precipitation regime change (increased soil moisture) in the gap area [4,5]. Illumination of the forest gap largely depends on the size of the gap and the size of the surrounding tree stand. Large trees shade the edges of the forest gap and, if the gap is small, can shade it almost in full [3]. The amount of light that reaches the floor of the forest gap also depends on the latitude at which the gap is located, the slope of the terrain, and its position on the sunny or shady side. All three items affect the angle of incidence of sunlight. The amount of incoming light also varies depending on the season and daily rhythm [5–8]. The greater the gap, the more surface is exposed to light. Air temperature largely depends on location exposure to sunlight and wind. Kermavnar et al. [5] showed that the microclimate in Dinaric fir-beech forests also depends on topographic factors (i.e., within-sinkhole position). Temperature fluctuations in forest gaps are greater than those in a compact forest [9]. Higher daily and seasonal fluctuations in air temperatures were also shown by Kermavnar et al. [5]. A forest gap has higher soil humidity than the forest, as it is directly exposed to precipitation [3]. Humidity

depends on the amount of litterfall remaining in the forest gap after its formation. Woody debris (trunks, branches, leaves) retains moisture [3,8,10].

The forest dynamics in forest gaps are similar in all forest types and progress in the direction of overgrowing with tree species [2], but can also differ among gaps according to pre-disturbance biotic and abiotic conditions [11]. However, there is a difference in the rate of overgrowing and the species composition of the plants. At the beginning of a newly formatted forest gap, the trees growing on the edges of the forest gap start spreading their canopies towards the gap, i.e., where they have sufficient space. This is noticeable particularly in deciduous trees [12]. This is an edge effect that, in addition to the effect on light, also has an effect on the expansion of plants from the edge to the forest gap [8]. In forest gaps, the tree species that stagnated in the understory before the formation of the gap, where they did not have enough light to grow, begin growing more quickly. Specimens of some plant species adapted to a dense forest stand (growing there before gap formation) either die or adapt to new conditions [13], like *Cyclamen purpurascens*, in which the synthesis of anthocyanins is increased at forest gaps compared to a compact forest stand [14]. In deciduous forests of temperate climates, the first colonisers of forest gaps are spring flowering plant species (like *Omphalodes verna*) of the herbaceous layer from a nearby forest stand [15]. They begin their vegetation period when trees do not develop leaves yet and, of course, they retain this trait at forest gaps. In forest gaps near roads with high traffic, some invasive plant species can also occur [16].

For some seeds, a forest gap also represents a favourable environment for germination. The soil seed banks at the gaps as a form of post-disturbance regeneration are especially important for some herbaceous plant species. A forest gap represents a sink for seeds from near and far surroundings, carried there by winds, animals, or man [12]. The more successful colonisers of forest gaps include species that have long-lived seeds in a seed bank and species whose seeds can disperse over long distances [17]. Generally, the species whose seeds are spread by animals are more successful.

Shortly after the gap formation, the species richness is increasing and continues to rise over time, until the last stages of succession when the gap is again overgrown. Constantly changing abiotic and biotic factors, as well as interspecific relation over the years, cause species turnover. Some species disappear or decrease, others appear or increase, but at the beginning of the succession process on newly formed forest gaps, the species richness increases [17]. Forest gaps, as a result of disturbance, affect changes in the community structure which depend on the type [18] and intensity of the disturbance and interactions of various disturbances in time and space [19–22].

In relation to the occurrence of limiting stress factors (altered water and light regime, suboptimal temperature, change in the amount of nutrients) and the disturbance itself (partial or complete destruction of plant biomass), the strategy of the whole community in the forest gap changes, from the time of formation to overgrowing along the succession line [23]. Understanding the changes resulting from the formation of the forest gap in the forest ecosystem and its effects on local biodiversity can be very important for forest management [24].

Based on findings of other studies [2,9,16,25] describing the change of abiotic and biotic factors in forest gaps and general patterns of colonisation of plant species in forest gaps, our study examined the occurrence of plant species in the initial stages (immediately after disturbance) of newly formed forest gaps and of those older ones (after four years). However, we selected only forest gaps that were formed as a result of disasters and were, therefore, of different sizes. Disturbances, e.g., ice storms and windthrow, are increasingly common in forests due to climate changes, resulting in greater likelihood of forest gap formation [26]. In forest management, the question arises as to whether such newly formed areas should be actively managed or left to natural processes. By studying colonisation of such areas by plant species, we can obtain important data that will help in forest management and thus preserve the great biodiversity of the forest as an ecosystem.

The goal of our study was to determine the plant species population dynamics at forest gaps in Dinaric silver fir-beech forests (*Omphalodo-Fagetum*). We studied the plant species turnover at forest gaps, which is a result of colonised and resident plant species. Our study focused on species diversity, composition of plant community, and its ecological strategy in relation to the size and age of the forest gaps. We predicted:

- that plant species diversity would vary between specific forest gaps, depending on their age;
- that mostly plant species from surrounding the forest will spread to the forest gaps;
- there would be no significant appearance of invasive plants;
- that beech would be the most common tree species in forest gaps.

With the research, we want to enlighten about the natural succession and forest dynamics at naturally formed forest gaps. Our research could help forest management to make decisions about whether newly formed gaps should be planted with tree species or should be left to natural succession with higher plant diversity at the first stage of forest gap formation.

2. Materials and Methods

2.1. Study Sites

The study was conducted in Dinaric silver fir-beech forests (*Omphalodo-Fagetum*) in the southern part of Slovenia (Kočevje-Ribnica area). The geological substrate of the area is diverse soils changing in a small scale due to local topography and is formed predominantly by Jurassic and Cretaceous limestone and, to a lesser extent, dolomite. The surface in higher areas is drier because of shallow humus limestone soil (rendzina), which is formed on parent material, while more or less shallow brown soil formed in the lowlands.

The average annual rainfall in the lowlands is between 1400 and 1500 mm and, at higher altitudes, from 1600 mm to 2000 mm [27]. The two peak rainfall times usually occur in June and from September to October (www.meteo.arso.gov.si/met/sl/climate/maps/monthly-mean-precipitation-maps, accessed on 14 February 2022). The average annual temperature of the Kočevje-Ribnica area ranges between 7 °C and 9 °C in the lowlands and between 6 °C and 7 °C in the mountain range [27]. Weather phenomena include frequent sleet and wet snow, which cause trees to break and fall. Windthrow can occur in summer months due to a strong south-western wind [27,28]. Thunderstorm winds cause the most severe damage, but blowdown patches are typically limited to stand-scales (e.g., 10 s of ha). Ice storms and heavy snow typically cause intermediate severity damage and affect much larger areas [29]. Because of these weather phenomena and their consequences, the formation of forest gaps in this area is very common. Dinaric silver fir-beech forests of the studied area are part of the Dinaric phytogeographic region [30]. The area is characterised by Central European flora with a more or less strong influence of the Illyrian-Balkan flora and Alpine floral element [30–32].

For the purposes of our study, we selected six survey localities (L) within the research area (Figure 1), of which five were forest gaps that were formed at different times and of different sizes (other features are listed in Table 1) and one was in the stand of juvenile beech trees (with trunk diameter ≤ 10 cm) (Stone Wall). Namely in the rejuvenation phase of the stand, beech predominates, and only later the fir saplings develop under the beech [33]. The localities were chosen according to their position in the same region, (Kočevje-Ribnica area), similarities in gap formation, altitude, and exposition. We could not obtain exact data on their formation, so we estimated the age of forest gaps on the basis of the state of bigger organic decomposing material (trunks and branches) and the annual growth of spruce saplings (faster growth on sunlight and habitus of a single plant) [34–36]. All forest gaps formed as a result of natural disturbances (sleet or windthrow), which was determined on the basis of uprooted and decaying trees, the condition of tree trunks, and the size of the forest gap [37,38].



Figure 1. Locations of 6 sampling sites on map (1: Stone Wall, 2: Below Barnik, 3: Above Barnik, 4: Goteniški Snežnik, 5: Goteniška gora, 6: Above Draga). (Source: http://gis.arso.gov.si/atlasokolja/profile.aspx?id=Atlas_Okolja_AXL@Arso, accessed on 12 January 2022).

Table 1. Forest gaps and their features (coordinates, UTM quadrant, altitude, aspect, substrate, soil, year of origin). The location marked * is control site with juvenile phase of beech forest.

Locality/Forest Gap	Coordinates	Altit.	Ex.	Surface	Substrate	Year
L1 (Stone wall) *	Y: 5479575 X: 5052223	1068 m	SE	175 m ²	limestone	2000
L2 (Below Barnik)	Y: 5478774 X: 5051499	1132 m	SW	600 m ²	dolomite	2007
L3 (Above Barnik)	Y: 5478904 X: 5051210	1161 m	SE	1400 m ²	limestone, dolomite	2007
L4 (Goteniški Snežnik)	Y: 5480085 X: 5049403	1205 m	E	1300 m ²	limestone, dolomite	2013
L5 (Goteniška gora)	X: 5055948 Y: 5476338	1100 m	SE	3200 m ²	limestone, dolomite	2011
L6 (Above Draga)	Y: 5473400 X: 5052341	954 m	E	1480 m ²	dolomite	2014

2.2. Floristic Survey and Sampling

In 2016 and 2017, vegetation surveys were performed a total of nine times on all five forest gaps and in the beech stand in order to (Table 2) get a total species pool at localities

(hereafter they will be named with the locality number and year of creation, e.g., L1-2000). We conducted 9 surveys over three years because we wanted to obtain, during different seasons, a record of plant species as comprehensive as possible at each forest gap [39]. Floristic surveys at total forest gap area were done for a control, including how many and which species can we expect at a single gap. In addition, we estimated the spatial distribution of plant species at a single forest gap.

Table 2. Floristic surveys and sampling scheme.

Locality	Floristic Survey Dates	Sampling Dates and No. of Sampling Plots
L1 (Stone wall) *	24 August 2015 21 April, 7 June, 8 July, 3 August, 27 September 2016 29 March, 25 April, 24 May, 11 July 2017	11 July 2017/8 plots
L2 (Below Barnik)	24 August 2015 21 April, 7 June, 8 July, 3 August, 27 September 2016 29 March, 25 April, 24 May, 11 July 2017	11 July 2017/8 plots
L3 (Above Barnik)	24 August 2015 21 April, 7 June, 8 July, 3 August, 27 September 2016 29 March, 25 April, 24 May, 11 July 2017	11 July 2017/8 plots
L4 (Goteniški Snežnik)	24 August 2015 21 April, 7 June, 8 July, 3 August, 27 September 2016 29 March, 25 April, 24 May, 20 July 2017	20 July 2017/14 plots
L5 (Goteniška gora)	24 August 2015 21 April, 7 June, 8 July, 3 August, 27 September 2016 29 March, 25 April, 24 May, 12 July 2017	12 July 2017/20 plots
L6 (Above Draga)	24 August 2015 21 April, 7 June, 8 July, 3 August, 27 September 2016 29 March, 25 April, 24 May, 21 July 2017	21 July 2017/20 plots

During the last vegetation survey in 2017 (in July), we divided the forest gaps into 3-by-3-metre sample plots, which were evenly (systematically) distributed over the surface of each locality. The number of sample plots per locality/forest gap varied between individual gaps, as the forest gaps were of different sizes (Tables 1 and 2). We selected 8 sample plots at L1-2000 (beech stand), L2-2007, and L3-2007 forest gaps, 14 at the L4-2013 gap, and 20 at the L5-2011 and L6-2014 gaps. In each sample plot, we conducted a sampling using the Braun-Blanquet method [40] to get more objective sampling for statistical analyses (Table 2). We used the Braun-Blanquet cover score, which was then transformed in cover percentage in JUICE 7.0 software [40]. Only herb [41] and shrub layer were included in the recording. The sampling was done during the last floristic survey in July because, at that time, there is a peak of vegetation season.

2.3. Data Analysis

For the data analyses, we used data collected in sample plots. Analyses of plant species composition in sample plots at individual forest gaps (location) were conducted using the JUICE 7.0 software [42]. The calculation of parameters was based on averages calculated from all sample plots at a single locality (forest gap). Since we wanted to determine whether the coverage of the species present in a single forest gap is changing during succession, we calculated the minimum, maximum, and average cover of each species at each forest gap and the frequency of their occurrence in forest gaps. For species that occurred in at least five or six forest gaps (locations), and whose cover differed between locations, we used the Kruskal-Wallis test with Bonferoni correction for multiple comparisons in the Statistica 8.0 software [43] to calculate whether the difference in cover between individual forest gaps was statistically significant for these species ($p < 0.05$). The calculation was also based on data obtained in sample plots.

We attributed geoelements according to Pignatti et al. [44] to all species and calculated the share of species belonging to a specific geoelement. For each forest gap, we identified unique species, as well as diagnostic, constant, and dominant plant species [45]. For the fidelity threshold of diagnostic species, we chose the occurrence of the species in at least 50% of the sample plots at each locality compared to other localities (at phi between -1 and 1). A species was constant if it occurred in at least 60% of sample plots, and dominant when it had a cover of more than 30% on each sample plot. Incidental species were those that were present at only one sample plot [42]. The Fischer test in the JUICE 7.0 software was used to identify rare species [46]. To determine similarities in plant community (species composition) between forest gaps, we used the Jaccard similarity coefficients [39,47] and nearest neighbour amalgamation procedure, which were calculated using JUICE 7.0 (as Cluster Analysis–PC-ORD) [48] and plotted a dendrogram.

Using the BIOLFLOR database [49] and the C-S-R Signature Calculator 1.2 software [50], we determined the life strategy of plant communities at individual locality and produced a C-S-R diagram [23]. With the help of Ellenberg indicator values [51], we analysed the environmental factors of individual locality and consequently determined the ecological requirements of plant species that inhabit the studied forest gaps.

3. Results

3.1. Species Richness

A total of 184 different plant species were recorded in the herb layer together on all localities (forest gaps and beech stand) and a total of 140 species on all sample plots (78 plots of size 3×3). Comparatively among forest gaps, the highest number of species was found in the largest 5-year-old forest gap, L5-2011, namely, in the survey of entire locality, 106 and, in the surveys within single sample plot, 74 species. The fewest (84) were found on the smallest 9-year-old forest gap, L2-2007 (Table 3).

Table 3. Number of plant species at single locality (L1–2000; L2–2007; L3–2007; L4–2013; L5–2011; L6–2014).

	L1	L2	L3	L4	L5	L6
No. of all species per locality/forest gap	58	84	92	96	106	93
Only on individual locality	2	9	9	8	13	23
Only on sample plots	0	3	4	10	7	14
Only outside sample plots but at the locality	27	27	26	28	32	20

Of all the species, only one non-native invasive species (*Erigeron annuus*) was recorded. It was present at two forest gaps, with one or two specimens. The highest number of species present only at an individual forest gap was found at the youngest forest gap, L6-2014 (23), and the largest forest gap, L5-2011 (13) (Table 3).

Table 4. Cont.

Species	Diagnostic						Constant						Dominant					
	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6
<i>Rubus idaeus</i>								*	*	*	*		*					*
<i>Salvia glutinosa</i>		*									*			*				
<i>Sanicula europaea</i>							*		*			*			*			
<i>Scrophularia nodosa</i>		*												*				
<i>Senecio ovatus</i>							*	*	*	*	*							*
<i>Tussilago farfara</i>															*	*		
<i>Urtica dioica</i>															*			
<i>Veronica officinalis</i>															*			
<i>Vicia oroboides</i>			*															
<i>Viola canina</i>								*										

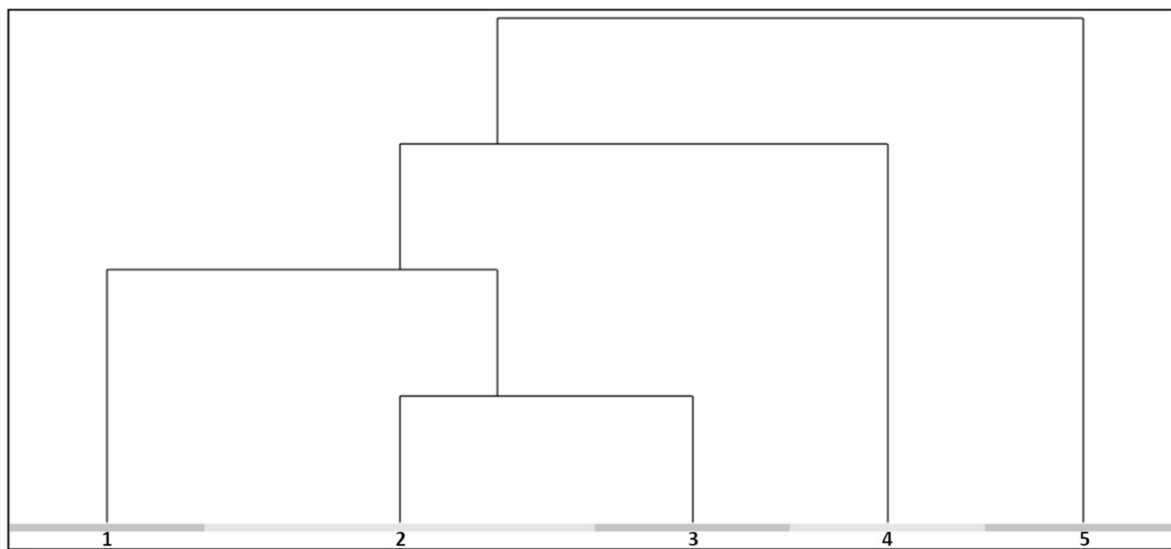


Figure 2. Dendrogram of similarities between individual locations based on Jaccard coefficient (1: control L1-2000; 2: L3-2007 and L4-2013; 3: L5-2011; 4: L2-2007; 5: L6-2014).

3.2. Analysis of Species Composition

At individual forest gaps, the cover of most plant species was less than 50% in the sample plots. In terms of forest gap age, at the youngest forest gap, L6-2014, and oldest, L5-2011, less than a quarter of species in the sample plots had average cover below 2% and at second youngest, L4-2013, even less. At L6-2014, *Epimedium alpinum* L. had the highest average coverage (21%) and at L4-2013, species *Fragaria vesca* L. (26%), *F. sylvatica* (25%), and *S. glutinosa* (22%). At the forest gap L5-2011, species *Tussilago farfara* L. (36%), *B. sylvaticum* (27%), and *F. vesca* (24%) had the highest average cover. This is followed by the oldest forest gaps, with species *T. farfara* (63%), *F. sylvatica* (38%), *B. sylvaticum* (22%), and *S. ovatus* (21%) having the highest percentage of average cover in the sample plots at the forest gap L2-2007. Comparing to other forest gaps, this forest gap had many more species with a cover of less than 2%. At the forest gap L3-2007, as many as one third of the species had an average cover of less than 2% in the sample plots, with species *Petasites albus* (L.) Gaertn. (55%) having high average cover in addition to species *F. sylvatica* (32%) and *B. sylvaticum* (44%). The highest average (at least 20% or more) and maximum cover (more than 60%) of species in total at all forest gaps are shown in Table 5. In terms of frequency of occurrence of species on sample plots, *F. sylvatica* (100%) and *A. pseudoplatanus* (above 60%) had the highest frequency at all localities, *Galium odoratum* (L.) Scop. (above 70%) and *Galeobdolon flavidum* (F. Herm.) (above 50%) at five localities and *B. sylvaticum* (over 70%) and *Carex sylvatica* Huds. and *F. vesca* at four localities with more than 50%.

Table 5. Plant species with highest average (at least 20% or more) and maximum (more than 60%) cover at all sample plots of studied forest gaps.

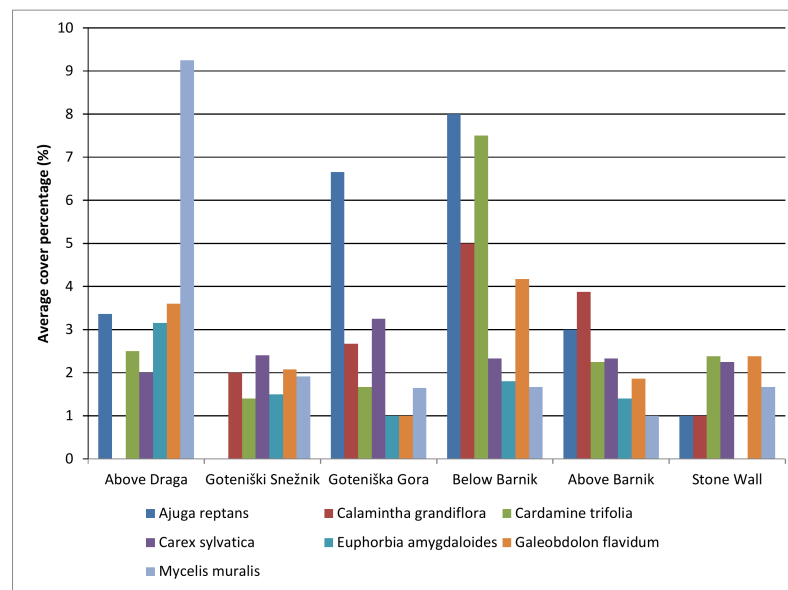
Average Cover in %	Maximum Cover in %
<i>Fagus sylvatica</i> (29%)	<i>Fagus sylvatica</i> (88%)
<i>Brachypodium sylvaticum</i> (24%)	<i>Brachypodium sylvaticum</i> (63%)
<i>Tussilago farfara</i> (20%)	<i>Tussilago farfara</i> (63%)
<i>Epimedium alpinum</i> (21%)	<i>Fragaria vesca</i> (63%)
	<i>Petasites albus</i> (63%)
	<i>Salvia glutinosa</i> (63%)
	<i>Senecio ovatus</i> (63%)

For 15 species that were present in the sample plots on most forest gaps, statistically significant differences in cover were observed between individual forest gaps (Figure 3a,b). Species *B. sylvaticum* had a statistically higher average cover on the forest gap L3-2007 compared to the forest gap L6-2014, where this species was not present at all, and from the beech stand L1-2000 and the forest gap L2-2007. For species *C. grandiflora*, there were statistically significant differences in the average cover between the site L3-2007 and the sites L5-2011, L4-2013, beech stand L1-2000, and L6-2014, but at L3-2007, this species had greater cover than at other sites. At L2-2007, species *Cardamine trifolia* L., *G. odoratum*, *Omphalodes verna* Moench and *S. ovatus* had a statistically significant highest cover of all in comparison to other five sites. At the site L6-2014, however, *Mercurialis perennis* L., *Mycelis muralis* (L.) Dumort. and *Euphorbia amygdaloides* L. had a statistically significant higher average cover than at the other five sites. While species *F. vesca* had a statistically significant higher average cover at the location L4-2013 compared to the locations L6-2014, beech stand L1-2000 and L2-2007, species *S. glutinosa* had, in addition to the same statistical differences as the previously mentioned species, significant differences in cover compared to locations L3-2007 and L5-2011. Species *Sanicula europaea* L. had characteristically the highest average cover at the site L5-2011 compared to the beech stand L1-2000, L3-2007, L4-2013, and L2-2007. For species *A. reptans*, there were statistically significant differences only between the sites L5-2011 and L4-2013, where its average cover was significantly lower or was absent. Species *C. sylvatica* and *G. flavidum* also had a significantly different cover on L5-2011. The first one had the highest cover and the second one, the lowest cover on L5-2011. The first one had a significantly higher average cover there than at the location L6-2014, and the latter, the lowest compared to the location L2-2007.

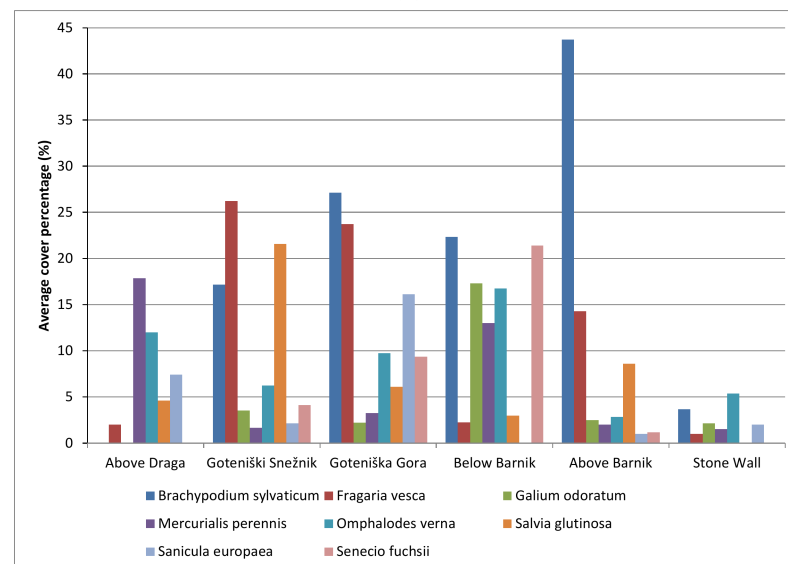
3.3. Analysis of Environmental Factors and Ecological Strategy of Community

Based on Ellenberg phytoindication estimates of environmental variables, we found that the Ellenberg light index at all studied forest gaps was between 4 and 5, temperature index between 4.8 and 5.2, and humidity index between 5 and 5.4. In the Ellenberg index that describes the pH of the soil, there were differences between the forest gap L6-2014 and others. At the forest gap L6-2014, it was 7, while in the other four forest gaps, it was between 6 and 7. In terms of the amount of nitrogen and other nutrients in the soil, the average Ellenberg index was between 5.5 and 6 for four locations and between 6 and 6.5 for two locations. According to the Ellenberg continentality index, which was between 3 and 4 on forest gaps, forest gaps in the studied area are mainly inhabited by plant species widespread in Central Europe.

By analysing the ecological strategy of plant communities, we found that plant communities have a stress tolerator–competitor/competitor–stress tolerator–ruderal (SC/CSR) strategy in most of the studied forest gaps. Only the plant community at the forest gap L2-2007 differs slightly, as it has a competitor/competitor–stress tolerator–ruderal (C/CSR) strategy. In all communities of studied forest gaps, the largest component is represented by strategy C (competitor), which has a share of over 45% in all of them (Figure 4).



(a)



(b)

Figure 3. (a) Cover percentage change diagram between single sampling sites for first set of 15 chosen plant species (Above Draga/L6-2014, Goteniški Snežnik/L4-2013, Goteniška gora/L5-2011, Below Barnik/L2-2007, Above Barnik/L3-2007, control Stone Wall/L1-2000). (b) Cover percentage change diagram between single sampling sites for second set of 15 chosen plant species (Above Draga/L6-2014, Goteniški Snežnik/L4-2013, Goteniška gora/L5-2011, Below Barnik/L2-2007, Above Barnik/L3-2007, control Stone Wall/L1-2000).

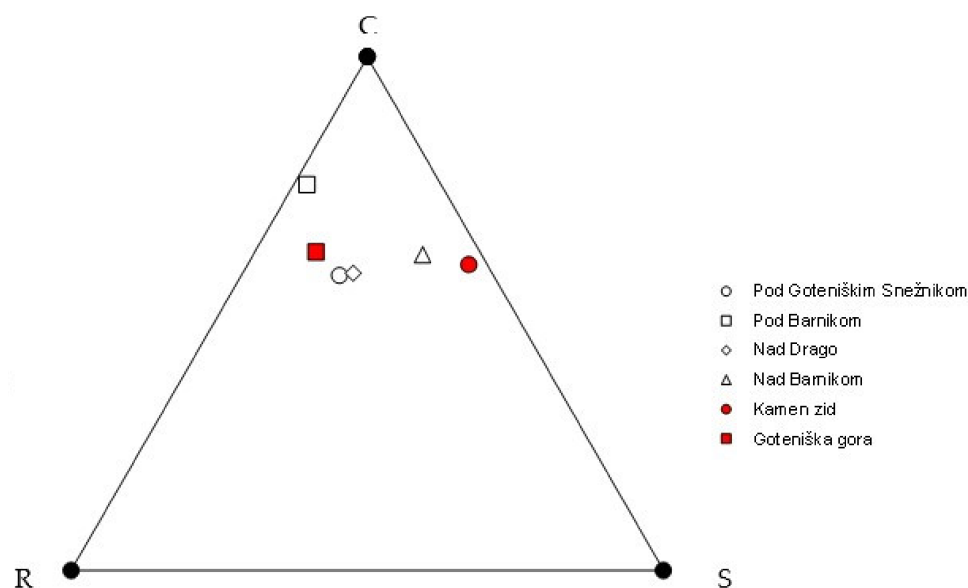


Figure 4. C-S-R strategy of plant communities at single sampling sites (L4-2013 (Pod Goteniškim Snežnikom), L2-2007 (Pod Barnikom), L6-2014 (Nad DRago), L3-2007 (Nad Barnikom), L1-2000 (Kamen zid), L5-2011 (Gotaniška gora)).

4. Discussion

In our study, we recorded a total of 186 species in forest gaps, which is much more than in a similar study in Hungary, where the largest number of species was 61 [2,52]. We can, therefore, conclude that the plant species diversity in forest gaps included in our study is rich and contributes to the impact on the biodiversity of the entire area [53]. This can already be explained by the high α -diversity (local diversity) of individual forest gaps, which in turn leads to high β -diversity (ratio between regional and local diversity) [47]. Therefore, forest gaps L5-2011 and L2-2007 provide support for the fact that the size of the forest gap affects its biodiversity [7,14,53]. At the first one, we recorded the largest number of species, which is due to the fact that it is the largest of all gaps and its mosaic structure, which is a result of a natural disturbance, provides many microhabitats for the growth of plant species with different ecological niches [14]. Some shade species (e.g., *O. verna*, *M. perennis*, *Maianthemum bifolium* (L.) F. W. Schmidt) were still present at this gap, representing the remnants of forest understory species [54], while species of sunny habitats were predominant on shallow soils and locations exposed to the sun. Furthermore, next to decaying organic material, we observed species that thrive on nutrient-rich soils (e.g., *Urtica dioica* L., *R. idaeus*) [55] and representatives of species with high stalk plants, characteristic of forest gaps (e.g., *S. glutinosa*, *S. nodosa*, *S. ovatus*) [54]. A higher degree of mineralisation occurs in the initial stages of forest gaps, as the disturbance causes more decomposing organic material on the ground [56]. The opposite was found out for the smallest forest gap, L2-2007. Lower species number is the influence of the canopy of edge trees. Specifically, in this forest gap, there appear no plants of sunny habitats because the canopies of edge trees form shade over most of the forest gap [2,7,16].

The species present in our studied forest gaps were mostly species of forest understory, forest edge, and clear-fells [14,53]. There were almost no meadow species, which is logical since the studied forest gaps are located in the middle of forests, and there are no such meadow surfaces nearby that could be a source of meadow plant species colonisation. Some meadow species, e.g., *Bellis perennis* L., *Plantago major* L., *Medicago lupulina* L., *Crepis biennis* L., and *Taraxacum officinale* Weber in Wiggers, probably spread to forest gaps through forest roads and trails, which are used for wood harvesting and are connected to non-forest surfaces [57]. These species were predominantly located along forest trails. Colonisation of non-forest species along roads and trails to forest gaps also represents a potentially dangerous possibility for transfer of invasive plant species, so biodiversity along paths

should be regularly monitored in forest management to promptly prevent the introduction of invasive species. However, at each of the forest gaps, we recorded a few species that appeared only there and nowhere else. We surveyed most of such species (23) at the forest gap L6-2014. The reason for this could be that this forest gap is the farthest from all the others. Therefore, the floristic composition of the surroundings (as a source of colonising species) of the forest gap L6-2014 may be different from those surrounding areas of other forest gaps [58]. The other reason is also that the gap was formed the most recently. This forest gap also had a larger share of annuals and biennials, which are mainly pioneer species—this is characteristic mainly of the initial phase of succession [12].

The species that were present at all forest gaps can be classified into two groups, specifically those that are typical representatives of beech forest understory (e.g., *O. verna*, *C. trifolia*, *C. sylvatica*, *G. flavoidum*, *E. amygdaloides*, *M. muralis*, *S. europaea*) [59,60] and those that are common representatives of forest edges and clearings (e.g., *F. vesca*, *S. glutinosa*, *Scrophularia nodosa*, *R. idaeus*) [61]. Differences in their cover between individual forest gaps, however, indicate that the age and size of the forest gaps have an impact on their occurrence and spread. Namely, the greater cover of species *M. perennis*, *H. epipactis*, and *E. alpinum* at the forest gap L6-2014 again indicates that this forest gap was still in formation phase at the time of the study, as the forest understory species had the largest cover. These again represent the remnants of species that grew under canopy before the felling of trees and forest gap formation [16,53,62]. This is also confirmed by the statistically significant higher cover of forest understory species *M. muralis* and *E. amygdaloides* (in addition to *M. perennis*) at the site L6-2014. The same was found in the study by Kermavnar et al. [12]. At the forest gap L2-2007, shade-loving species (forest understory species) had a statistically significant higher cover because this forest gap is the smallest and longest and, consequently, shadier. These species of forest understory in forest gaps are, in a way, remnants of the former beech forest [12], which still thrive primarily on the shadier parts of forest gaps, and are, therefore, characteristic of newly formed forest gaps. However, they reappear in the final stages of succession overgrowing, when tree vegetation begins overgrowing the forest gap [16]. For species of forest edges, the forest gaps represent a new favourable environment, to which they colonise from already existing forest edges. These species thus tolerate more open surfaces with more light, as well as partial shade. These are species that are present on forest gaps of medium age [2,6,53,63].

However, the low cover of plant species (at least one third of the species on forest gaps did not exceed cover of 2%) indicates that the plant species on forest gaps did not appear in larger closed populations. Small cover of species allows the coexistence of a larger number of species, increasing the biodiversity of the site [14,53]. Species, which appeared with the highest cover on all forest gaps, except the youngest one, L6-2014, were *F. sylvatica*, *T. farfara*, *B. sylvaticum*, *F. vesca*, *S. glutinosa*, *P. albus*, and *S. ovatus*. The gap L6-2014 was at the beginning of succession and species did not yet develop bigger populations. The high cover of *F. sylvatica* is expected, as it represents the predominant tree species in all locations. Species *B. sylvaticum* is also a common species in forests. The greater cover of species *T. farfara* and *P. albus* indicates their pioneer character and morphological adaptations, which allow them to propagate rapidly (production of large quantity of seeds and propagation by rhizomes) primarily on moist limestone soils with rock debris [63].

The frequency of occurrence on the sample plots and the constancy of specific species confirmed their uniform even distribution on the entire surface of the forest gaps, as the sample plots were evenly distributed on the forest gaps. The uniform representation of a species on the surface can again be either the result of environmental factors (uniform influence of the environmental factor on the entire surface) or the adaptability of a specific species to various environmental factors. One third of the species were present in more than 50% of the sample plots of an individual forest gap, i.e., they were more or less evenly distributed on the forest gaps. Their share varied slightly between forest gaps. On the forest gap L2-2007 thrive most such species, probably because of its small size, which resulted in lower fluctuations of environmental factors. Species *S. ovatus* stood out with its 100%

frequency of occurrence at three forest gaps. We can conclude that this species has a wide ecological niche. It appeared on all sample plots, both on the smallest and shadiest forest gap, L2-2007, as well as on the largest forest gap with a very mosaic structure, L5-2011, and on the nutrient-rich forest gap, L4-2013. Its broad ecological valence is also cited in the literature. It is even said to be a typical species of forest gaps formed after fires, snow damage, and blowdowns [54,64].

According to Ellenberg indices, we found that forest gaps are colonised primarily by semi-shady plant species that grow in places with more than 10% light intensity, but rarely thrive in full light and are characteristic of moderately warm and submontane areas [51]. These are also species that thrive on moderately moist to dry soils, as forest gaps are open surfaces where fluctuations in humidity are greater. The surface of all forest gaps is also structured into pit and mound, with humidity being higher in pit with accumulated organic material than in raised, exposed parts [65–67]. The mosaic structure thus allows those species that need slightly more moisture to thrive as well as those that grow in dry habitats. According to Ellenberg indices, differences between forest gaps became apparent in the amount of nutrients in the soil, which is the result of the gap formatting time and the decaying plant material left there after the disturbance. On L5-2011 and L4-2013, there were several species that grow in soils richer in nutrients, which is the result of a larger amount of litterfall (branches, trunks, stumps) that is in the last stage of decomposition at both forest gaps. As decomposition increases, the pH of the soil decreases [68,69], which we determined by the Ellenberg index. Therefore, plant species growing on soils with medium to weak acidity are present at all forest gaps except the youngest (L6-2014). At the youngest forest gap, Ellenberg soil pH index determined the presence of plant species growing on moderately acidic to weakly alkaline soils. The reason for this is that decomposition of organic material after ice storms and salvage harvesting is only in its initial phase.

Every newly formed forest gap can represent a new area either for colonisation by plant species or for increasing the population of species already present there. Competitively more successful plant species occupy the surface with sufficient resources faster or their population there increases more rapidly [47]. Due to the larger amounts of decomposing plant material in the soil, there are enough nutrients and also enough light for photosynthesis in the studied forest gaps. Therefore, when studying the ecological strategy of communities at all forest gaps, we found the most pronounced competitor component of the C-S-R diagram that characterises the community of plant species with a competitor strategy [23]. At the same time, it is classified as a community that has a stress-tolerator strategy [70]. The opposite was found by Eller et. al. [71], where the C-S-R strategy shifted from stress-tolerators in pre-logging conditions to a more ruderal component in post-logging stands (when the forest gap was formed). One reason for differences in research could be that, in our research, the gaps were in the middle of dense forest stands and there were no donor populations of ruderal plant species around, and the second reason is that our forest gaps, except one Above Draga, were not newly formed gaps and were not at the beginning of succession. Additionally, in our research, we chose naturally formed forest gaps, and in aforementioned research of Eller et al. [71], they were formed by logging. The difference between gap forming is that, with logging, process machines damage the understory vegetation and forest floor. The 'opened' floor patches are then suitable environments for ruderal species. The same happens on forest gaps where high digging activity of bigger forest mammals is present [15]. With natural gap formatting and leaving the trunks and fallen wood on the floor, there are fewer 'opened' floor patches and a less suitable environment for ruderal species.

The study confirmed the complexity of colonisation of forest gaps by plant species. The characteristics of plant species colonisation in gaps is that, in the initial stage of a gap (after formation of a gap), the most common species are sciophytic plants, which represent the remaining forest understory and ruderal species. With time, an older gap starts to be colonised by heliophytic plant species (representative of species with tall stems), with greater populations of grasses and sedges. Tree species start growing on gap edges,

primarily beech in the Dinaric fir-beech forests. The species that grow in forest gaps prefer habitats with more sunlight, medium wet to dry soil, and are tolerant to high daily and seasonal temperature fluctuations, but at same time, forest gaps are a habitat patch for some species that did not exist there before. Colonisation, as well as species turnover, occurs very quickly with the change of environment in the process of overgrowing. Forest gaps also represent important windows of increased biodiversity and the chance for forest regeneration. Regrowth is fast enough, so there is no need for additional planting on formed forest gaps.

5. Conclusions

In the forest ecosystem, forest gaps represent an important developmental stage of the forest and a habitat for certain plant species. In our research, we found that the species composition and distribution of plants at forest gaps are significantly influenced by the size of forest gaps, their greater or lesser structure in microenvironment, amount of woody debris, abiotic factors, plant species composition of nearby forest gaps, and colonisation pathways.

In our study, we found greater biodiversity of plant species at forest gaps compared to the juvenile beech stand. The number of species was highest at the largest of the forest gaps. We found that the investigated forest gaps inhabit mostly species of forest understory, forest edges, and felling. The species present at all forest gaps are typical representatives of the beech forest understory, as well as common representatives of forest edges. Forest understory species are only remnants of former compacted forest before the forest gaps formatting, which thrive mainly on the shadier parts of forest gaps.

Plant species typical of forest understory have a greater cover on newly emerging forest gaps. In older forest gaps (4 years and older), there is a species turnover, where species typical of more open areas have a greater coverage. Populations of forest understory species are beginning to decrease, while populations of grasses, sedges, and other plant species typical of open areas are beginning to increase.

The plant species composition of an individual forest gap largely depends on the proximity of donor populations. Our studied forest gaps were inhabited by plant species characteristic of temperate and submontane areas. Characteristics of species that colonise forest gaps are preference for sites with more light, with moderately moist to dry soils, and tolerance to large daytime, night, and seasonal temperature fluctuations. Those forest gaps, on which more decaying plant material is present, are inhabited by species that need more nutrients in the soil to grow. Due to this, forest gaps colonisation with plant species is also significantly influenced by the amount of decaying plant material.

Author Contributions: Conceptualization, B.R. and J.B.; methodology, B.R. and J.B.; formal analysis, B.R. and A.Č.; investigation, B.R. and J.B.; writing—original draft preparation, B.R.; writing—review and editing, J.B. and A.Č.; visualization, B.R. and A.Č. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Helms, J.A. *The Dictionary of Forestry*; Society of American Foresters and CABI Publishing: Bethesda, MD, USA, 1998; 210p.
2. Frelich, L.E. *Forest Dynamics and Disturbance Regimes*; Cambridge University Press: Cambridge, UK, 2002; 90p.
3. Gálhidy, L.; Mihok, B.; Hagyo, A.; Rajkai, K.; Standovár, T. Effects of gap size and associated changes in light and soil moisture on the understorey vegetation of a Hungarian beech forest. *Plant Ecol.* **2006**, *183*, 133–145. [[CrossRef](#)]
4. Vilhar, U.; Roženberger, D.; Simončič, P.; Diaci, J. Variation in irradiance, soil features and regeneration patterns in experimental forest canopy gaps. *Ann. For. Sci.* **2015**, *72*, 253–266. [[CrossRef](#)]
5. Kermavnar, J.; Ferlan, M.; Marinšek, A.; Eler, K.; Kobler, A.; Kutnar, L. Effects of various cutting treatments and topographic factors on microclimatic conditions in Dinaric fir-beech forests. *Agric. For. Meteorol.* **2020**, *295*, 108–186. [[CrossRef](#)]

6. Latif, Z.A.; Blackburn, G.A. The effects of gap size on some microclimate variables during late summer and autumn in a temperate broadleaved deciduous forest. *Int. J. Biometeorology* **2010**, *54*, 119–129. [[CrossRef](#)] [[PubMed](#)]
7. Seyednasrollah, B.; Kumar, M. Net radiation in a snow-covered discontinuous forest gap for a range of gap sizes and topographic configurations. *J. Geophys. Res. Atmos.* **2014**, *10*, 323–342. [[CrossRef](#)]
8. O'Hara, K. *Multitaged Silviculture: Managing for Complex Forest Stand Structures*; Published to Oxford Scholarship Online: Oxford, UK, 2014; 262p.
9. Duguid, M.C.; Frey, B.R.; Ellum, D.S.; Kelty, M.; Ashton, M.S. The influence of ground disturbance and gap position on understory plant diversity in upland forests of southern New England. *For. Ecol. Manag.* **2013**, *303*, 148–159. [[CrossRef](#)]
10. Kollár, T. Light Conditions, Soil Moisture, and Vegetation Cover in Artificial Forest Gaps in Western Hungary. *Acta Silv. Et. Lignaria Hung.* **2017**, *13*, 25–40. [[CrossRef](#)]
11. Kermavnar, J.; Eler, K.; Marinšek, A.; Kutnar, L. Post-harvest forest herb layer demography: General patterns are driven by pre-disturbance conditions. *For. Ecol. Manag.* **2021**, *491*, 119–121. [[CrossRef](#)]
12. Feldmann, E.; Dröbner, L.; Hauck, M.; Kucbel, S.; Pichler, V.; Leuschner, C. Canopy gap dynamics and tree understory release in a virgin beech forest, Slovakian Carpathians. *For. Ecol. Manag.* **2018**, *415–416*, 38–46. [[CrossRef](#)]
13. Kermavnar, J.; Eler, K.; Marinšek, A.; Kutnar, L. Initial understory vegetation responses following different forest management intensities in Illyrian beech forest. *Appl. Veg. Sci.* **2019**, *22*, 48–60. [[CrossRef](#)]
14. Ravnjak, B.; Bavcon, J.; Oster, G. Physiological response of local populations of species *Cyclamen purpurascens* Mill. To forest gaps. *Appl. Ecol. Environ. Res. Int. Sci. J.* **2019**, *17*, 11489–11508. [[CrossRef](#)]
15. Fahey, R.T.; Puettmann, K.J. Ground-layer disturbance and initial conditions influence gap partitioning of understorey vegetation. *J. Ecol.* **2007**, *95*, 1098–1109. [[CrossRef](#)]
16. Collins, B.S.; Dunne, K.P.; Pickett, S.T.A. Responses of Forest Herbs to Canopy Gaps. In *The Ecology of Natural Disturbance and Patch Dynamics*; Pickett, S.T.A., White, P.S., Eds.; Academic Press: London, UK, 1985; pp. 217–234.
17. Kelemen, K.; Mihók, B.; Gálhidy, L. Dynamic response of herbaceous vegetation to gap opening in a central European beech stand. *Silva Fenn.* **2012**, *46*, 53–65. [[CrossRef](#)]
18. Vukelić, J.; Mikac, S.; Baričević, D.; Šapić, I.; Bakšić, D. Vegetation and structural features of Norway spruce stands (*Picea abies* Karst.) in the virgin forest of Smrčeve doline in northern Velebit. *Croat. J. For. Eng. J. Theory Appl. For. Eng.* **2011**, *32*, 85–86.
19. Schoennagel, T.; Smithwick, E.A.H.; Turner, M.G. Landscape heterogeneity following large fires: Insights from Yellowstone National Park, USA. *Int. J. Wildland Fire* **2008**, *17*, 742–753. [[CrossRef](#)]
20. Bottero, A.; Garbarino, M.; Dukic, V.; Goveda, Z.; Lingu, E.; Nagel, T.A.; Motta, R. Gap-phase dynamics in the old-growth forest of Lom, Bosnia and Herzegovina. *Silva Fenn.* **2011**, *45*, 875–887. [[CrossRef](#)]
21. Muscolo, M.; Bagnato, S.; Sidari, M.; Mercurio, R. A review of the roles of forest canopy gaps. *J. For. Res.* **2014**, *25*, 725–736. [[CrossRef](#)]
22. Hilmers, T.; Friess, N.; Bäessler, C.; Heurich, M.; Brandl, R.; Pretzsch, H.; Seidl, R.; Müller, J. Biodiversity along temperate forest succession. *J. Appl. Ecol.* **2018**, *55*, 2756–2766. [[CrossRef](#)]
23. Grime, J.P. Evidence for the existence of three primary strategies in plants and its relevance to ecological and evolutionary theory. *Am. Nat.* **1997**, *3*, 1169–1194. [[CrossRef](#)]
24. Meterc, G.; Skudnik, M.; Jurc, M. Vpliv gospodarjenja na biotsko raznovrstnost saproksilnih hroščev [The impact of forest management to the biodiversity of saproxylic beetles]. *Gozdarski Vestn.* **2015**, *73*, 3–18.
25. Honnay, O.; Hermy, M.; Coppin, P. Impact of habitat quality on forest plant species colonization. *For. Ecol. Manag.* **1999**, *115*, 157–170. [[CrossRef](#)]
26. Dale, V.H.; Joyce, L.A.; McNulty, S.; Neilson, R.P.; Ayres, M.P.; Flannigan, M.D.; Hanson, P.J.; Irland, L.C.; Lugo, A.E.; Peterson, C.J.; et al. Climate Change and Forest Disturbance: Climate change can effect forests by altering the frequency, intensity, duration, and timing of fire, drought, introduced species, insects and pathogen outbreaks, hurricanes, windstorms, ice storms or landslides. *BioScience* **2001**, *51*, 723–734. [[CrossRef](#)]
27. Slovenian Environment Agency—ARSO. *Podnebne Razmere v Sloveniji (Obdobje 1985–2010) [Weather Conditions in Slovenia (Period 1985–2010)]*; Slovenian Environment Agency: Ljubljana, Slovenia, 2010; 27p.
28. Kordiš, F. *Dinarski Jelovo-Bukovi Gozdovi v Sloveniji [Dinaric Silver Fir-Beech Forests in Slovenia]*; Biotechnical Faculty, Department of Forestry: Ljubljana, Slovenia, 1993; 139p.
29. Nagel, T.A.; Mikac, S.; Dolinar, M.; Klopčič, M. The natural disturbance regime in forests of the Dinaric Mountains: A synthesis of evidence. *For. Ecol. Manag.* **2017**, *388*, 29–42. [[CrossRef](#)]
30. Wraber, M. Pflanzengeographische Stellung und Gliederung Sloweniens. *Vegetatio* **1969**, *17*, 176–199. [[CrossRef](#)]
31. Wraber, M. Vegetacija slovenskega bukovega gozda v luči ekologije in palinologije. *Biološki Vestn.* **1964**, *12*, 77–95.
32. Praprotnik, N. *Ilirski Florni Element v Sloveniji. Doktorska Disertacija*; Univerza Edvarda Kardelja v Ljubljani, Biotehniška fakulteta, VTOZD za biologijo: Ljubljana, Slovenia, 1987; 234p.
33. Marinček, L. *Bukovi Gozdovi na Slovenskem [Beech Forests in Slovenia]*; Delavska Enotnost: Ljubljana, Slovenia, 1987; 153p.
34. Fraver, S.; Wagner, R.G.; Day, M. Dynamics of coarse woody debris following gap harvesting in the Acadian forests of central Maine, U.S.A. *Can. J. For. Res.* **2002**, *32*, 2094–2105. [[CrossRef](#)]
35. Müller-Using, S.; Bartsch, N. Decay dynamic of coarse and fine woody debris of a beech (*Fagus sylvatica* L.) forest in Central Germany. *Eur. J. For. Res.* **2009**, *128*, 287–296. [[CrossRef](#)]

36. Sefidi, K.; Marvie Mohadjer, M.R. 2010: Characteristics of coarse woody debris in successional stages of natural beech forests (*Fagus orientalis*) of Northern Iran. *J. For. Sci.* **2010**, *56*, 7–17. [[CrossRef](#)]
37. Jakša, J. Natural disasters in Slovenian forest. *Gozdraski Vestn.* **2007**, *65*, 177–192.
38. Jakša, J. Natural disasters in Slovenian forest. *Gozdraski Vestn.* **2007**, *65*, 241–256.
39. Tarman, K. *Osnove Ekologije in Ekologija Živali*; Državna Založba Slovenije: Ljubljana, Slovenija, 1992; 547p.
40. Braun-Blanquet, J. *Pflanzensoziologie. Grundzüge der Vegetationskunde*; Springer: Berlin/Heidelberg, Germany, 1964; 330p.
41. Gilliam, F.S. The Ecological Significance of the Herbaceous Layer in Temperate Forest Ecosystems. *BioScience* **2007**, *57*, 845–858. [[CrossRef](#)]
42. Tichý, L. JUICE, software for vegetation classification. *J. Veg. Sci.* **2002**, *13*, 451–453. [[CrossRef](#)]
43. Zur, A.F.; Ieno, E.N.; Smith, G.M. *Analysing Ecological Data*; Springer: Berlin/Heidelberg, Germany, 2007; 672p.
44. Pignatti, S.; Menegoni, P.; Pietrosanti, S. Valori di bioindicazione delle piante vascolari della flora d'Italia [Bioindicator values of vascular plants of the Flora of Italy]. *Braun-Blanquetia* **2005**, *39*, 1–97.
45. Jarolímek, I.; Šibík, J. *Diagnostic, Constant and Dominant Species of the Higher Vegetation Units in Slovakia*; VEDA: Bratislava, Slovakia, 2008; 329p.
46. Sokal, R.R.; Rohlf, F.J. *Biometry*, 3rd ed.; W.H. Freeman: New York, NY, USA, 1995.
47. Smith, R.L.; Smith, T.M. *Ecology & Field Biology*; Benjamin Cummings: San Francisco, CA, USA, 2001; 771p.
48. Tichy, L.; Holt, J. *JUICE Program for Management Analysis and Classification of Ecological Data*; Vegetation Science Group, Masaryk University Brno: Brno, Czech Republic, 2006; 98p.
49. Klotz, S.; Kühn, I.; Durka, W. *BIOLFLOR—Eine Datenbank zu Biologisch-Ökologischen Merkmalen der Gefäßpflanzen in Deutschland—Schriftenreihe für Vegetationskunde 38*; Bundesamt für Naturschutz: Bonn, Germany, 2002.
50. Hunt, R.; Hodgson, J.G.; Thompson, K.; Bungener, P.; Dunnett, N.P.; Askew, A.P. A new practical tool for deriving a functional signature for herbaceous vegetation. *Appl. Veg. Sci.* **2004**, *7*, 163–170. [[CrossRef](#)]
51. Ellenberg, H.; Weber, H.E.; Düll, R.; Wirth, V.; Werner, W.; Paulissen, D. *Zeigerwerte von Pflanzen in Mitteleuropa*; Erich Goltze: Göttingen, Germany, 1992; 262p.
52. Večeřa, M.; Divišek, J.; Lenoir, J.; Jiménez-Alfaro, B.; Biurrún, I.; Knollova, I.; Agrillo, E.; Campos, J.A.; Čarni, A.; Crespo, G.; et al. Alpha diversity of vascular plants in European forests. *J. Biogeogr.* **2019**, *46*, 1919–1935. [[CrossRef](#)]
53. Degen, T.; Devillez, F.; Jacquemart, A.-L. Gaps promote plant diversity in beech forests (Luzulo-Fagetum), North Vosges, France. *Ann. For. Sci.* **2005**, *62*, 429–440. [[CrossRef](#)]
54. Šilić, Č. *Šumske Zeljaste Biljke*; Zavod za Udžbenike i Nastavna Sredstva: Beograd, Serbia, 1988; 271p.
55. Taylor, K. Biological Flora of the British Isles: *Urtica dioica* L. *J. Ecol.* **2009**, *97*, 1436–1458. [[CrossRef](#)]
56. Mayer, M.; Matthews, B.; Rosinger, C.; Douglas, H.S.; Godbold, L.; Katzensteiner, K. Tree regeneration retards decomposition in a temperate mountain soil after forest gap disturbance. *Soil Biol. Biochem.* **2017**, *115*, 490–498. [[CrossRef](#)]
57. Čarni, A. Vegetation of trampled habitats in the Prekmurje region (NE Slovenia). *Hacquetia* **2005**, *4*, 151–159.
58. Burton, J.I.; Mladenoff, D.J.; Clayton, M.K.; Jodi, A.; Forrester, J.A. The roles of environmental filtering and colonization in the fine-scale spatial patterning of ground-layer plant communities in north temperate deciduous forests. *J. Ecol.* **2011**, *99*, 764–776. [[CrossRef](#)]
59. Willner, W.; Jimenez-Alfaro, B.; Agrillo, E.; Biurrún, I.; Campos, J.A.; Čarni, A.; Cassela, L.; Csiky, J.; Čušterevska, R.; Didukh, Y.P.; et al. Classification of European beech forests: A Gordian Knot? *Appl. Veg. Sci.* **2017**, *20*, 494–512. [[CrossRef](#)]
60. Zupančič, M.; Vreš, B. Phytogeographic analysis of Slovenia. *Folia Biol. Geol.* **2018**, *59*, 160–211.
61. Mucina, L.; Buelmann, H.; Dierßen, K.; Theurillat, J.P.; Raus, T.; Čarni, A.; Šumberová, K.; Willner, W.; Dengler, J.; Gavilán, R.; et al. Vegetation of Europe: Hierarchical floristic classification system of vascular plant, bryophyte, lichen, and algal communities. *Appl. Veg. Sci.* **2016**, *19*, 3–264. [[CrossRef](#)]
62. Kermavnar, J. *Vplivi Gospodarjenja na Funkcionalne Lastnosti Gozdne Vegetacije in Ekološke Razmere v Dinarskih Jelovo-Bukovih Gozdovih* [Impacts of Forest Management on Functional Properties of Vegetation and Ecological Conditions in the Dinaric Fir-Beech Forests]. Ph.D. Thesis, Biotechnical Faculty, University of Ljubljana, Ljubljana, Slovenia, 2021; 225p.
63. Myerscough, P.J.; Whitehead, F.H. Comparative biology of *Tussilago farfara* L.; *Chamaenerion angustifolium* (L.) Scop., *Epilobium montanum* L. and *Epilobium adenocaulon* Hausskn. *Gen. Biol. Germination* **1965**, *1*, 192–210.
64. Rahmonov, O.; Jędrzejko, K.; Majgier, L. The secondary succession in the area of abandoned cemeteries in northern Poland. In *Landscape Ecology—Methods, Applications and Interdisciplinary Approach*; Barančoková, M., Krajčí, J., Kollár, J., Belčáková, J., Eds.; Institute of Landscape Ecology, Slovak Academy of Sciences: Bratislava, Slovakia, 2010; pp. 647–657.
65. Ulanova, N. The effects of windthrow on forest at different spatial scales: A review. *For. Ecol. Manag.* **2000**, *135*, 155–167. [[CrossRef](#)]
66. Mollaei Darabi, S.; Kooch, Y.; Hosseini, S. Dynamic of Plant Composition and Regeneration following Windthrow in a Temperate Beech Forest. *Int. Sch. Res. Not.* **2014**, *2014*, 1–9. [[CrossRef](#)]
67. Marinšek, A.; Celarc, B.; Grah, A.; Kokalj, Ž.; Nagel, T.A.; Ogris, N.; Planinšek, Š.; Roženbergar, D.; Veljanovski, T.; Vochl, S.; et al. Žledolom in njegove posledice na razvoj gozdov—Pregled dosedanjih znanj [Impacts of Ice Storms on Forest Development—A Review]. *Gozdarski Vestn.* **2015**, *73*, 392–405.
68. Kraigher, H.; Jurc, D.; Kalan, P.; Kutnar, L.; Levanič, T.; Rupel, M.; Smolej, I. Beech coarse woody debris characteristic in two virgin forests reserves in southern Slovenia. *Zb. Gozdarstva Lesar.* **2002**, *69*, 91–134.

69. Spears, J.D.H.; Lajtha, K. The imprint of coarse woody debris on soil chemistry in the western Oregon Cascades. *Biogeochemistry* **2004**, *71*, 163–175. [[CrossRef](#)]
70. Bavcon, J. *Belo Cvetiče Različice v Slovenski Flori [White-Flowered Varieties in Slovenian Flora]*; University Botanic Gardens Ljubljana: Ljubljana, Slovenia, 2014; 349p.
71. Eler, K.; Kermavnar, J.; Marinšek, A.; Kutnar, L. 2018: Short-term changes in plant functional traits and understory functional diversity after logging of different intensities: A temperate fir-beech forest experiment. *Ann. For. Res.* **2018**, *61*, 223–242. [[CrossRef](#)]