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**Research Article**

# Phytogeographical and biological spectrum of vascular flora as an indicator of ecological changes following clear-cutting in Eastern Serbian beech forest sites

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## Abstract

Extreme weather events caused considerable harm to the forest ecosystems in Eastern Serbia over a few hard winters, resulting in widespread ice breaks and ice uprooting. Certain forest stands were severely impacted during the winter of 2014-2015, necessitating clear-cutting measures. This research was conducted in the Timok forest area, through examination of the floristic composition in areas subjected to clear-cutting, including natural beech forests and artificially established conifer stands within beech sites (*Helleboro odori-Fagetum moesiacae*). A phytogeographical and bioecological analysis was conducted five years after clear-cutting. Changes in ecosystems were assessed by analysing the spectra of area-types and plant life forms, with comparisons drawn to the "Vinatovača" old-growth forest, situated in the submontane beech forest of Eastern Serbia. Descriptive analysis of the phytogeographical and bioecological spectra of vascular flora, alongside multinomial correspondence analysis, revealed an increased presence of species from Eurasian, Mediterranean-sub-Mediterranean, and Pontic area-types, as well as hemicryptophytic, phanerophytic, and therophytic life forms in the clear-cut areas. In contrast, the old-growth forest was colonised by species of Central European and Holarctic area-types, along with geophytic life forms. These findings suggest a shift towards xerothermic microclimates in the clear-cut areas and the stronger influence of the continental climate of Eastern Serbia with its extremes on deforested areas, as well as on the processes of forest ecosystem degradation.

***Keywords:*** clear-cutting; ice breaks and ice uproots; life forms spectrum and phytogeographical spectrum; Serbia; vascular flora

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## Introduction

During the winter of 2014-2015, forest ecosystems and infrastructure facilities within the broader region of Eastern Serbia suffered extensive damage due to extreme weather conditions. Depending on the vegetation types and orographic conditions, the damage in the form of ice breaks and ice uproots varied in intensity. According to the rehabilitation plan, artificially established conifer stands within beech sites were almost completely devastated, while natural stands suffered partial to complete damage. (Pavlović *et al.*, 2023). According to Baković *et al.* (2015), significant damage occurred in the Timok, Morava, North Kučaj, Rasina, and South Kučaj forest areas. The extreme weather disaster particularly affected two forest areas – Moravsko and Timočko, necessitating clear-cutting on approximately 2,000 hectares of heavily affected stands (Pavlović *et al.*, 2022). In February 2014, an ice storm in the Gorski Kotar region caused extensive damage, affecting 43,025 hectares of state-owned forests, including Risnjak National Park, and 9,723 hectares of private forests. The total volume of damaged timber was estimated at 4,269,077 m$^3$.

Similarly, significant damage was reported in Slovenia, where the Slovenian Forest Service estimated the impact at 9,300,000 m$^3$ of timber, equivalent to €214,000,000 (Saje, 2014). Storms, including wind and snow, cause more than 50% of all forest damage in Europe. Snow and ice damage occurs every 1 to 10 years in different parts of Europe (Gardiner, 2014). Freezing rain in Europe typically occurs between November and February (Carrière *et al.*, 2000) with higher frequency in Central and Eastern Europe (typically 2–3 events annually) than in Northern Europe (typically 0.5–2 events annually) (Kämäräinen *et al.*, 2017). In many parts of Europe, ice storms are likely more common than reported (Bernstein *et al.*, 2009), since they are mostly of low intensity and cause no or minor damage (Klopčič *et al.*, 2020). The February 1994 storm produced heavy ice accumulations in northern Mississippi and caused severe damage across parts of nine states (Lott and Ross, 1994). This storm affected much timber, including damage to 1 500 000 ha of forest and heavy losses to urban trees and pecan orchards, marking it as the most destructive ice storm in Mississippi since 1931 (Irland, 2000).

The typical montane beech forest (*Helleboro odori-Fagetum moes*iacae Soo & Borhidi 1960) belongs to the subassociation of montane beech forests (*Helleboro odori-Fagenion moesiacae* Soo & Borhidi 1960). These forests occur at low elevations within the oak zone, predominantly influenced by orographic conditions, and within the belt of climate-regional beech and beech-fir forests of the *Fagion moesiacae* Blečić et Lakušić 1976 alliance. This association is widespread in Serbia, particularly in the Pannonian region, Šumadija, and eastern Serbia (Tomić *et al.*, 2017). Montane beech forests are conditioned by orographic and edaphic factors, typically occurring in the oak belt at (40) 250-600 (1000) meters above sea level, where they represent a stable vegetation stage (Cvjetićanin, 2003). This community is noted as typical of lower elevations in Serbia (Dzwonko *et al.*, 2000).

This study focuses on natural stands of submontane beech *Helleboro odori-Fagetum moesiacae* Soo & Borhidi 1960 (Tomić *et al.*, 2011) and artificially established stands within this forest community site, examining ecological changes in beech sites five years after clear-cutting in the Timok forest area.

The subject of this work is the ecological changes of beech habitats five years after clear felling, in the area of the "Timočki forest area". Spectra of flora elements and plant life forms can indicate these changes. Spontaneously settled plants, as indicators, indicate changes in ecological (primarily microclimatic and edaphic) conditions.

The goal of the research is to establish to what extent the habitat has been changed after clear cutting and what are the possibilities to regeneration the forest ecosystem on the cuttings as it was before the elemental weather disaster through the succession of vegetation in a natural way.

Following clear-cutting, artificial regeneration was undertaken in selected areas through planting of various species of broadleaved and coniferous trees, while other areas were left to undergo natural renewal. Upon revisiting these sites five years later, it was evident that artificial regeneration had achieved only limited success, with spontaneous natural vegetation prevailing across most of the clear-cut areas. Spontaneously colonised plants serve as indicators of ecological changes, particularly in microclimatic and edaphic conditions.

## Materials and Methods

### *Study area*

To assess changes in forest ecosystems five years after clear-cutting, eight sample plots, each covering an area of 1000 m$^2$, were established within beech sites of the Timok forest area. Sample plots are presented in Table 1.

**Table 1.** Study area with spatial data of sample plots (SP)

| SP | MU | COMP./SEC | Coordinate | |
|---|---|---|---|---|
| | | | X | Y |
| 1 | Zaglavak I | 28b | 7616006 | 4836924 |
| 2 | Tresibaba | 46b | 7600595 | 4815354 |
| 3 | Šaška-Studena-Selačka Reka | 40c | 7612882 | 4840854 |
| 4 | Šaška-Studena-Selačka Reka | 25a | 7612842 | 4844570 |
| 5 | Čestobrodica | 90g | 7561912 | 4849575 |
| 6 | Rtanj | 29a | 7575116 | 4847134 |
| 7 | Rtanj | 28c | 7575688 | 4847047 |
| 8 | Čestobrodica | 100/1 | 7563705 | 4847579 |

Table 1 provides details regarding management units (MU) and compartments and sections (COMP/SECT) where sample plots (SP) were established. Each sample plot is presented with coordinates. Four sample plots were placed in areas that had natural stands before clear-cutting, while the remaining four were in areas where coniferous stands, primarily spruce, black pine, and white pine, had been artificially established within the beech sites. These coniferous cultures were approximately 40 years old.

The locations selected for the sample plots were well-suited for observing vegetation succession patterns and the potential for restoring the original indigenous forest stands.

### *Data collection and analysis*

Basic ecological conditions were defined within the sample plots, and phytosociological surveys were conducted employing a sampling methodology to provide an overview of the floristic composition in areas affected by clear-cutting. The analysis of floristic composition was carried out across various stand types, categorised based on the conservation status of the forest ecosystem (old-growth beech forest – clear-cut natural beech forest – clear-cut artificially established stands within beech sites), as well as across different bedrocks (limestone and silicate rocks). Due to the absence of phytocoenology surveys in the same areas before clear-cutting, the obtained results were compared with the spectra of floral elements and life forms in the "Vinatovača" old-growth forest, also located in a submontane beech forest of Eastern Serbia (Čokeša *et al.*, 2022). This comparison aimed to evaluate the deviation of highly degraded ecosystems from a completely natural old-growth forest ecosystem. Plant species identification was conducted using keys from the "Flora of Serbia", volumes 1-9 (Josifović 1970, 1977).

The classification of each taxon in the clearcuts and the old-growth forest into specific area-types, area-groups, and floristic elements was determined according to Meusel *et al.* (1965, 1978) and Meusel and Jäger (1992), adapted by Stevanović (1992) for the territory of Serbia. The analysis of the present life forms was conducted following Raunkiaer (1934), supplemented by Mueller-Dombois and Ellenberg (1974), with further elaboration for taxa in Serbia by Stevanović V. (1992). For some taxa, area-types and life forms were specified based on Zlatković (2011) and Brković (2015).

Following this, a phytogeographical and biological analysis was performed including spectra of area-types and life forms to observe their absolute and relative frequencies.

### *Statistical tests*

By employing multinomial correspondence analysis, the association of phytogeographical, biological, and ecological characteristics of plants was tested to understand the nature of site changes five years after clear-cutting.

## Results and Discussion

The results include tabular and graphical representations of the basic ecological conditions, floristic composition, phytogeographical and biological analysis. Ecological condition is presented in Table 2. It includes basic ecological parameters such as altitude (ALT), aspect, average slope, origin, bedrock and soil type. Regarding stand conditions, the origin is specified distinguishing between natural beech stands and artificially established stands (AES) within beech sites.

**Table 2.** Ecological conditions

| SP | MU | COMP./SEC | ALT | Aspect | Slope (°) | Origin | Bedrock | Soil type |
|---|---|---|---|---|---|---|---|---|
| 1 | Zaglavak I | 28b | 695 | W-WS | 20 | AES | amphibole-biotite plagiogranites | Cambisol Dystric |
| 2 | Tresibaba | 46b | 714 | N | 10 | natural | limestone | Cambisol Calcaric |
| 3 | Šaška-Studena-Selačka Reka | 40c | 761 | SW | 30 | AES | amphibole-biotite plagiogranites | Cambisol Dystric |
| 4 | Šaška-Studena-Selačka Reka | 25a | 823 | NW | 25 | natural | phyllites and greenstones | Cambisol Dystric |
| 5 | Čestobrodica | 90g | 582 | N-NE | 12 | natural | organogenic limestone | Cambisol Calcaric |
| 6 | Rtanj | 29a | 779 | N | 25 | AES | limestone | Cambisol Calcaric |
| 7 | Rtanj | 28c | 675 | NE | 5 | AES | limestone breccia | Cambisol Calcaric |
| 8 | Čestobrodica | 100/1 | 575 | E | 32 | natural | conglomerates and sandstones | Cambisol Dystric |

Table 3, found in the appendix, offers a comprehensive overview of all vascular plant species in both the clear-cut areas and the "Vinatovača" old-growth forest. The table presents the phytogeographical, biological, and specific ecological characteristics of each species. The vascular flora in the clear-cut areas is listed by species. Besides the species name, it includes its area-type (area-group) based on various sources (Meusel *et al.* 1965, 1978, 1992), Stevanović (1992a); Zlatković (2011); Brković (2015) and life form (Raunkier, 1934; Stevanović, 1992; Zlatković, 2011; Brković, 2015). Furthermore, it provides details on stand types and bedrock. The designation "virg" indicates plants found in the old-growth forest, while "natur" and "plant" refer to stand types of the forest before clear-cutting which is currently a clear-cut area covered with spontaneous vegetation. "natur" denotes a clear-cut area in a natural beech forest site, whereas "plant" signifies a clear-cut area with artificially established conifer stands within the beech site. The final column denotes the bedrock, with "Ca" representing carbonate and "Si" silicate bedrock.

**Table 3.** Floristic composition

| Species | Area-type area-group (AT) | Life form (LF) | Stand type (ST) | Bedrock (B) |
|---|---|---|---|---|
| *Acer campestre* L. | CE | P MesP scap | plant, natur | Ca, Si |
| *Acer platanoides* L. | CE | P MesP scap | virg, plant | Ca, Si |
| *Acer pseudoplatanus* L. | CE | P MesP scap | virg, plant, natur | Ca, Si |
| *Achillea millefolium* L. | HOL | H scap | plant, natur | Ca, Si |
| *Actaea spicata* L. | CE | G rhiz | virg | Ca |
| *Aegopodium podagraria* L. | EURAS eur-(W)as | G rhiz | plant | Ca |
| *Agrimonia eupatoria* L. | EURAS euras | H scap | natur | Ca |
| *Ajuga genevensis* L. | CE | H semiros | plant | Si |
| *Ajuga reptans* L. | CE | H rept | natur | Ca |
| *Alliaria petiolata* (M.Bieb.) Cavara & Grande | EURAS euras | T scap | virg, natur | Ca |
| *Allium ursinum* L. | CE | G bulb | virg | Si, Ca |
| *Alopecurus pratensis* L. | EURAS euras | T caesp | natur, plant | Ca |
| *Anemone nemorosa* (L.) Holub | CE | G rhiz | virg | Ca |
| *Anemone ranunculoides* (L.) Holub | CE | G rhiz | virg | Ca, Si |
| *Anthriscus sylvestris* (L.) Hoffm. | COSM | H scap | natur | Si |
| *Anthyllis vulneraria* L. | CE | H caesp | natur | Ca |
| *Arctium lappa* L. | EURAS euras | H bienn scap | natur | Ca |
| *Aremonia agrimonoides* (L.) DC. | CE | H ros | virg, plant | Ca, Si |
| *Artemisia vulgaris* L. | EURAS euras | H scap | natur, plant | Ca |
| *Arum maculatum* L. | EURAS eur-(W)as | G rhiz | virg | Ca, Si |
| *Asarum europaeum* L. | CE | Ch herb rept | virg, natur | Ca, Si |
| *Asplenium adiantum-nigrum* L. | COSM | G rhiz | virg | Ca |
| *Asplenium seterach* L. | MED-SUBM | H ros | virg | Ca |
| *Asplenium scolopendrium* L. | HOL | Ch herb caesp | virg | Ca |
| *Asplenium trichomanes* L. | COSM | Ch herb caesp | virg | Ca |
| *Astragalus glycyphyllos* L. | CE | H rept | plant | Ca |
| *Athyrium filix-femina* (L.) Roth | HOL | G rhiz | virg | Si, Ca |
| *Atropa bella-donna* L. | EURAS eur-(W)as | H scap | natur, plant, virg | Ca |
| *Bellis perennis* L. | CE | H ros | natur | Ca |
| *Brachypodium pinnatum* (L.) P.Beauv. | EURAS euras | H caesp | virg | Ca |
| *Brachypodium sylvaticum* (Huds.) P.Beauv. | EURAS euras | H caesp | virg, plant, natur | Ca, Si |
| *Briza media* L. | COSM | H caesp | natur | Ca |
| *Bromus sterilis* L. | EURAS euras | T caesp | plant | Si |
| *Calamagrostis epigejos* (L.) Roth | EURAS euras | H caesp | natur | Ca |
| *Campanula persicifolia* L. | CE | H scap | plant | Ca |
| *Campanula rapunculoides* L. | EURAS euras | H scap | virg | Ca |
| *Cardamine bulbifera* (L.) Crantz | CE | H scap | virg, natur, plant | Ca, Si |
| *Carduus acanthoides* L. | COSM | H bienn scap | natur | Ca |
| *Carduus nutans* L. | PONT | H bienn scap | plant | Ca |
| *Carex digitata* L. | CE | H caesp | virg | Ca |
| *Carex divulsa* Stokes | MED-SUBM | H caesp | plant | Si |
| *Carex hirta* L. | CE | H caesp | natur | Ca |
| *Carex pairae* F.W.Schultz | CE | H caesp | natur | Ca |
| *Carex pendula* Huds. | EURAS eur-(W)as | G rhiz | natur | Ca |
| *Carex pilosa* Scop. | EURAS med-(W)as | G rhiz | natur | Ca |
| *Carex sylvatica* Huds. | EURAS euras | H caesp | natur | Ca |
| *Carpinus betulus* L. | CE | P MesP scap | virg, plant, natur | Ca, Si |
| *Cephalanthera damasonium* (Mill.) Druce | MED-SUBM | G tub | virg | Ca |
| *Chaerophyllum temulum* L. | CE | H bienn scap | virg, natur | Ca |
| *Chamaecytisus hirsutus* (L.) Link | MED-SUBM | Ch frut caesp | plant | Ca |
| *Chamaecytisus leiocarpus* (A.Kern.) Rothm. | MED-SUBM | Ch frut caesp | plant | Si |
| *Chelidonium majus* L. | EURAS euras | H semiros | virg | Ca |
| *Chrysosplenium alternifolium* L. | HOL | T scap | virg | Si |
| *Circaea lutetiana* L. | CE | H scap | virg | Ca |
| *Cirsium arvense* (L.) Scop. | EURAS euras | H scap | natur, plant | Ca, Si |
| *Cirsium vulgare* (Savi) Ten. | COSM | H bienn scap | natur | Ca, Si |

| | | | | |
|---|---|---|---|---|
| *Clematis vitalba* L. | CE | S lig | natur, plant | Ca, Si |
| *Clinopodium vulgare* L. | HOL | H scap | plant, virg, natur | Ca, Si |
| *Cornus sanguinea* L. | CE | P MiP caesp | natur, plant | Ca, Si |
| *Coronilla varia* L. | CE | H scap | plant | Ca |
| *Corydalis solida* (L.) Clairv. | CE | G tub | virg | Ca |
| *Corylus avellana* L. | CE | P MiP caesp | virg, natur, plant | Ca, Si |
| *Corylus colurna* L. | CE | P MesP scap | plant | Ca |
| *Crataegus monogyna* Jacq. | CE | P MiP caesp | plant, natur | Ca, Si |
| *Cruciata laevipes* Opiz | CE | H scap | plant | Ca |
| *Cynoglossum germanicum* Jacq. | EURAS euras | H bienn scap | virg | Ca |
| *Cystopteris fragilis* (L.) Bernh. | HOL | G rhiz | virg | Ca |
| *Dactylis glomerata* L. | COSM | H caesp | plant, natur | Ca, Si |
| *Daphne blagayana Freyer* (Ch frut rept / EAM sjep) | EAM sjep | Ch frut rept | virg | Ca |
| *Daucus carota* L. | MED-SUBM | H bienn scap | natur | Ca |
| *Digitalis ferruginea* L. | CE | H ros | plant, natur | Ca, Si |
| *Digitalis grandiflora* Mill. | CE | H ros | natur, plant | Si, Ca |
| *Dioscorea communis* (L.) Caddick & Wilkin | MED-SUBM | S G herb | natur, plant | Ca |
| *Doronicum columnae* Ten. | EAM sjep | G rhiz | virg | Ca |
| *Dryopteris filix-mas* (L.) Schott | HOL | G rhiz | virg, plant, natur | Ca, Si |
| *Elymus repens* (L.) Gould | COSM | G rhiz | plant | Ca |
| *Epilobium angustifolium* L. | HOL | H scap | natur, plant | Ca, Si |
| *Epilobium montanum* L. | CE | H scap | virg | Ca |
| *Epipactis helleborine* (L.) Crantz | EURAS euras | G rhiz | virg | Ca |
| *Erythronium dens-canis* L. | CE | G bulb | virg | Ca |
| *Euonymus europaeus* L. | CE | P NP caesp | virg, natur | Ca, Si |
| *Euphorbia amygdaloides* L. | CE | Ch herb caesp | natur, virg | Ca, Si |
| *Euphorbia cyparissias* L. | CE | H scap | plant | Ca, Si |
| *Euphorbia helioscopia* L. | COSM | T scap | natur | Ca |
| *Euphorbia salicifolia* Host | PONT | H scap | plant | Si |
| *Euphorbia verrucosa* L. | MED-SUBM | H scap | natur, plant | Ca |
| *Fagus sylvatica* L. | CE | P MesP scap | virg, natur, plant | Ca, Si |
| *Fallopia convolvulus* (L.) Á.Löve | COSM | S T herb | plant | Si |
| *Festuca drymeja* Mert. & W.D.J.Koch | CE | H caesp | natur, plant, virg | Ca, Si |
| *Festuca valesiaca* Schleich. ex Gaudin | PONT | H caesp | natur, virg | Ca, Si |
| *Fragaria vesca* L. | EURAS euras | H rept | natur, plant, virg | Ca, Si |
| *Fraxinus excelsior* L. | CE | P MesP scap | virg, plant | Ca |
| *Fraxinus ornus* L. | MED-SUBM | P MesP scap | plant, natur | Ca, Si |
| *Galium album* Mill. | CE | H scap | plant | Ca, Si |
| *Galium aparine* L. | COSM | S T herb | virg, natur, plant | Ca, Si |
| *Galium corrudifolium* Vill. | MED-SUBM | H scap | plant | Ca |
| *Galium mollugo* L. | CE | H scap | natur, plant | Si, Ca |
| *Galium odoratum* (L.) Scop. | CE | H scap | virg, natur, plant | Ca, Si |
| *Galium sylvaticum* L. | CE | H scap | virg, natur | Ca |
| *Galium verum* L. | EURAS euras | H scap | plant | Si |
| *Genista ovata* Waldst. & Kit. | PONT | Ch frut caesp | plant | Si |
| *Geranium macrorrhizum* L. | EAM sjep | G rhiz | virg | Ca |
| *Geranium robertianum* L. | HOL | H bienn scap | virg, plant, natur | Ca, Si |
| *Geum urbanum* L. | EURAS euras | H scap | natur, plant | Ca, Si |
| *Hedera helix* L. | CE | S lig | virg, plant | Ca |
| *Helleborus odorus* Waldst. & Kit. ex Willd. | CE | G rhiz | natur, plant | Ca |
| *Hepatica nobilis* Schreber | CE | H Semiros | virg | Ca |
| *Hieracium murorum* L. | CE | H Semiros | virg, plant | Ca, Si |
| *Holcus lanatus* L. | COSM | H caesp | plant | Ca, Si |
| *Hordelymus europaeus* (L.) Jess. ex Harz | CE | H caesp | virg, natur, plant | Ca, Si |
| *Hypericum hirsutum* L. | EURAS euras | H scap | natur | Ca |
| *Hypericum perforatum* L. | EURAS euras | H scap | plant, natur | Ca, Si |
| *Isopyrum thalictroides* L. | CE | G rhiz | virg | Ca, Si |

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|---|---|---|---|---|
| *Juglans regia* L. | MED-SUBM | P MesP scap | plant, natur | Ca, Si |
| *Lactuca muralis* (L.) Gaertn. | CE | T scap | virg, plant | Ca |
| *Lamium galeobdolon* (L.) L. | CE | H scap | virg, natur | Ca, Si |
| *Lamium maculatum* L. | CE | H scap | virg | Ca |
| *Lapsana communis* L. | EURAS eur-(W)as | T scap | natur, virg | Ca, Si |
| *Lathyrus pratensis* L. | EURAS euras | H scap | plant, natur | Ca |
| *Lathyrus venetus* (Mill.) Wohlf. | CE | H scap | virg, natur, plant | Ca |
| *Lathyrus vernus* (L.) Bernh. | EURAS euras | H scap | virg | Ca |
| *Leucanthemum vulgare* Lam. | EURAS euras | H scap | natur, plant | Si, Ca |
| *Leucojum vernum* L. | CE | G bulb scap | Virg | Si, Ca |
| *Lilium martagon* L. | CE | G bulb | virg | Ca |
| *Linaria vulgaris* Mill. | EURAS euras | T scap | natur, plant | Si, Ca |
| *Lithospermum officinale* L. | PONT | H scap | plant | Ca |
| *Lonicera xylosteum* L. | EURAS eur-(W)as | P MiP caesp | virg | Ca |
| *Lunaria annua* L. | MED-SUBM | T scap | virg | Ca |
| *Lunaria rediviva* L. | CE | G rhiz | virg | Ca |
| *Luzula luzuloides* (Lam.) Dandy & Wilmott | CE | H caesp | plant | Si |
| *Lychnis coronaria* (L.) Desr. | MED-SUBM | H semiros | plant | Si, Ca |
| *Lysimachia punctata* L. | MED-SUBM | H scap | natur | Ca |
| *Mahonia aquifolium* (Pursh) Nutt. | ADV adv | P NP caesp | plant | Ca |
| *Malus sylvestris* (L.) Mill. | EURAS med-(W)as | P MesP scap | natur | Ca |
| *Melica uniflora* Retz. | CE | H caesp | plant, natur, virg | Ca, Si |
| *Melissa officinalis* L. | EURAS euras | H bienn scap | natur | Ca |
| *Mentha longifolia* (L.) L. | HOL | H scap | natur | Ca |
| *Mercurialis perennis* L. | CE | H scap | virg, plant | Ca, Si |
| *Moehringia muscosa* L. | EAM sjep | Ch herb rept | virg | Ca |
| *Myosotis sylvatica* Ehrh. ex Hoffm. | MED-SUBM | T scap | natur, virg | Ca, Si |
| *Neottia nidus-avis* (L.) L. C. M. Richard | EURAS eur-(W)as | G par | virg | Si |
| *Oxalis acetosella* L. | EURAS euras | G rhiz | virg | Ca |
| *Parietaria officinalis* L. | MED-SUBM | H scap | virg | Ca |
| *Paris quadrifolia* L. | EURAS euras | G rhiz | virg | Ca |
| *Persicaria hydropiper* (L.) Delarbre | COSM | T scap | natur | Ca |
| *Phleum pratense* L. | CE | H caesp | plant | Ca |
| *Plantago lanceolata* L. | COSM | H ros | natur | Ca |
| *Platanthera bifolia* (L.) Rich. | EURAS euras | G tub | virg | Ca |
| *Platanthera chlorantha* (Custer) Rchb. | CE | G tub | virg | Ca |
| *Poa nemoralis* L. | EURAS euras | H caesp | virg, natur, plant | Ca, Si |
| *Poa pratensis* L. | HOL | H caesp | plant | Ca |
| *Polygonatum multiflorum* (L.) All. | EURAS eur-(W)as | G rhiz | virg, plant | Ca |
| *Polygonatum odoratum* (Mill.) Druce | CE | G rhiz | virg | Ca, Si |
| *Polypodium vulgare* L. | HOL | G rhiz | virg | Ca |
| *Polystichum aculeatum* (L.) Roth | BOR | G rhiz | virg | Ca |
| *Polystichum setiferum* (Forssk.) T.Moore ex Woynar | CE | G rhiz | virg | Ca, Si |
| *Populus tremula* L. | EURAS euras | P MesP scap | natur | Ca |
| *Potentilla argentea* L. | EURAS euras | H scap | plant | Si |
| *Potentilla micrantha* Ramond ex DC. | MED-SUBM | H ros | plant | Si |
| *Prunella vulgaris* L. | HOL | H scap | natur | Ca |
| *Prunus avium* (L.) L. | CE | P MesP scap | plant, natur, virg | Ca, Si |
| *Prunus cerasifera* Ehrh. | PONT | P MiP caesp | natur, virg | Ca |
| *Prunus spinosa* L. | CE | P NP caesp | plant, natur | Ca, Si |
| *Pseudoturritis turrita* (L.) Al-Shehbaz | MED-SUBM | H bienn scap | virg, plant | Ca, Si |
| *Pteridium aquilinum* (L.) Kuhn | COSM | G rhiz | plant, natur | Ca, Si |
| *Pulmonaria officinalis* L. | CE | H scap | virg, natur | Ca, Si |
| *Pyrus pyraster* (L.) Burgsd. | CE | P MesP scap | natur, plant | Si, Ca |
| *Quercus cerris* L. | MED-SUBM | P MesP scap | natur, plant | Si, Ca |
| *Quercus petraea* (Matt.) Liebl. | CE | P MesP scap | plant, natur | Ca, Si |

| | | | | |
|---|---|---|---|---|
| *Rabelera holostea (L.)* M.T.Sharples & E.A.Tripp | EURAS eur-(W)as | Ch herb rept | natur | Ca |
| *Ranunculus acris* L. | EURAS euras | H semiros | plant | Ca |
| *Ranunculus lanuginosus* L. | CE | H semiros | natur | Ca |
| *Robinia pseudoacacia* L. | ADV adv | P MesP scap | plant, natur | Ca, Si |
| *Rorippa pyrenaica* (All.) Rchb. | MED-SUBM | H semiros | natur, plant | Si, Ca |
| *Rosa canina* L. | EURAS euras | P NP caesp | natur, plant | Ca, Si |
| *Rubus caesius* L. | EURAS euras | P NP rept | natur, plant | Si, Ca |
| *Rubus fruticosus* L. | HOL | P NP rept | plant | Si |
| *Rubus hirtus* Waldst. & Kit. | CE | P NP rept | virg, natur, plant | Ca, Si |
| *Rubus idaeus* L. | HOL | P NP rept | plant, natur | Si, Ca |
| *Rumex acetosella* L. | HOL | H scap | plant, natur | Si, Ca |
| *Rumex sanguineus* L. | EURAS eur-(W)as | H scap | natur | Ca, Si |
| *Salix caprea* L. | EURAS euras | P MiP scap | natur, plant | Ca, Si |
| *Salix fragilis* L. | EURAS euras | P MesP scap | natur | Ca |
| *Salvia glutinosa* L. | EURAS eur-(W)as | H scap | virg, plant, natur | Ca, Si |
| *Sambucus ebulus* L. | EURAS euras | G rhiz | natur, plant | Ca, Si |
| *Sambucus nigra L.* | CE | P MiP caesp | virg, natur, plant | Ca, Si |
| *Sanguisorba minor* Scop. | EURAS euras | H ros | natur, plant | Ca, Si |
| *Sanicula europaea* L. | CE | H semiros | natur, virg, plant | Ca |
| *Saxifraga rotundifolia* L. | EAM eam | H ros | virg | Ca |
| *Scilla bifolia* L. | CE | G bulb | virg | Ca |
| *Scrophularia nodosa* L. | EURAS euras | H scap | natur, plant, virg | Ca, Si |
| *Sedum maximum* (L.) Hoffm. | EURAS euras | Ch herb scap succ | virg | Ca |
| *Silene nutans* L. | EURAS euras | H ros | plant | Ca |
| *Silene vulgaris* (Moench) Garcke | EURAS euras | H semiros | natur, plant | Si, Ca |
| *Smyrnium perfoliatum* L. | MED-SUBM | H scap | natur | Ca |
| *Solanum dulcamara* L. | EURAS euras | S lig | virg | Si |
| *Solidago virgaurea* L. | HOL | H semiros | virg | Ca |
| *Sorbus torminalis* (L.) Crantz | CE | P MesP scap | plant, virg | Si, Ca |
| *Stachys germanica* L. | EURAS eur-(W)as | H scap | natur, plant | Ca |
| *Stachys sylvatica* L. | CE | H scap | virg, natur, plant | Ca, Si |
| *Stellaria graminea* L. | EURAS euras | H scap | plant | Ca |
| *Syringa vulgaris* L. | EURAS eur-(W)as | P MiP caesp | virg, plant | Ca |
| *Tanacetum vulgare* L. | EURAS euras | H scap | natur | Ca |
| *Taraxacum officinale* Weber v-aut | COSM | H ros | virg, natur, plant | Ca |
| *Thlaspi arvense* L. | EURAS euras | T scap | natur | Ca |
| *Tilia platyphyllos* Scop. fo dec | CE | P MesP scap | virg, natur, plant | Ca, Si |
| *Tilia tomentosa* Moench | CE | P MesP scap | plant, natur | Ca, Si |
| *Tragopogon dubius* Scop. | EURAS eur-(W)as | T scap bienn | plant | Ca |
| *Trifolium alpestre* L. | CE | H scap | plant | Si |
| *Trifolium arvense* L. | EURAS euras | T scap | plant | Si |
| *Trifolium medium* L. | EURAS eur-(W)as | G rhiz | plant | Ca, Si |
| *Trifolium pratense* L. | EURAS euras | H scap | plant | Si |
| *Turritis glabra* L. | HOL | H bienn scap | plant | Si |
| *Ulmus glabra* Hudson | CE | P MesP scap | virg | Ca |
| *Ulmus minor* Mill. | CE | P MesP scap | plant | Si |
| *Urtica dioica* L. | HOL | H scap | virg, natur, plant | Ca, Si |
| *Valeriana montana* L. | CE | Ch sufrr | virg | Ca |
| *Valeriana officinalis* L. | EURAS euras | H scap | plant | Ca |
| *Veratrum album* L. | EURAS euras | G bulb | plant | Ca |
| *Verbascum nigrum* L. | EURAS eur-(W)as | H bienn semiros | plant, natur | Ca, Si |
| *Verbascum phlomoides* L. | MED-SUBM | H bienn semiros | plant | Si, Ca |
| *Veronica chamaedrys* L. | EURAS euras | H scap | plant, natur, virg | Ca, Si |
| *Veronica montana* L. | CE | H rept | virg | Si |
| *Veronica officinalis* L. | HOL | H rept | natur, plant | Si, Ca |
| *Viburnum lantana* L. | CE | P MiP caesp | natur, plant | Ca |
| *Vicia cracca* L. | EURAS euras | S H herb | plant, natur | Ca, Si |

| | | | | |
|---|---|---|---|---|
| *Vincetoxicum hirundinaria* Medik. | MED-SUBM | H scap | natur, plant | Ca |
| *Viola canina* L. | EURAS euras | H semiros | plant, virg, natur | Ca, Si |
| *Viola hirta* L. | EURAS euras | H ros | virg, natur | Ca |
| *Viola tricolor* L. | EURAS euras | T scap | plant | Si |

Artificially established conifer stands exhibited poor management, with high slenderness coefficients, rendering them susceptible to extreme weather conditions. Cooper-Ellis *et al.* (1999) in the study on the reaction of the forest to the catastrophic wind, indicate the importance of the structure and composition of the forest before the weather disaster. The dense canopy cover resulted in the formation of a thin layer of moder-humus on the soil surface, accompanied by a markedly low diversity of ground flora. According to Burlica *et al.* (1983), clear-cut areas experience significant soil changes. The soil in these areas tends to be wetter during the wet season and drier during the dry season. Following clear-cutting, there is an initial increase in organic matter on the soil surface, which significantly declines within three years. The humus content in the humus-accumulative horizon decreases by 5% post-clear-cutting. Additionally, total nitrogen content decreases, with the C/N ratio narrowing during the first two years and widening in the third year. Mölder *et al.* (2008) and Mölder *et al.* (2014) report that pure beech forests exhibit lower ground flora diversity compared to mixed forests.

Five years after clear-cutting, some differences emerged between areas of natural beech stands and those with artificially established conifers on beech sites, as indicated by phytogeographical and biological analyses. Graphical representations and correspondence analysis reveal the grouping of plant species as indicators of altered ecological conditions.

In areas previously occupied by artificially established conifer stands, early successional woody species are more prevalent, whereas natural sites are richer in late successional woody species.

### *Phytogeographical analysis*

The analysed forests can be classified within the temperate climatic zone of Europe, where deciduous and mixed forests dominate (Horvat, 1949). The phytogeographical analysis covers all plants identified within the sample plots located in the Timok Forest Area and the “Vinatovača” old-growth forest. Floral elements are defined as area-types or area-groups, providing insight into the range of distribution of each plant species within the floristic zones in which they occur. For species whose ranges extend beyond the floristic realm, the abbreviated name of the area where they are found is accompanied by the range of floristic or climate-geographic zones these ranges cover (Brković, 2013). The spectra of plant area-types indicate changes in ecological conditions, primarily microclimatic, within the clear-cut areas. Categorising plant species based on phytogeographic affiliation (area-types, area-groups, and floral elements) reveals the climate-geographic zone where a species typically occurs. With changes in microclimatic conditions, plant species from different climatic regions colonise clear-cut areas, signalling the direction of ecological changes.

As depicted in Figure 1, the higher species count across nearly all area-types in the clear-cut areas results from their overall greater species richness. According to Schmidt (2005) and Smyčková *et al.* (2024), species diversity is higher in managed forests compared to old-growth forests. The same authors also report that species richness increased following natural disturbances such as windthrow and windbreaks, due to the greater canopy opening. Von Oheimb *et al.* (2007) observed a similar trend in beech forests in northern Germany, where an increase in the presence of vascular plants and *Bryophyta* was noted following windthrow and windbreak events, compared to undisturbed beech forests.

Based on the chorological analysis of the floristic composition, seven primary area-types were distinguished in the clear-cut areas and nine in the old-growth forest. The spectra of plant area-types present in the clear-cut areas and the old-growth forest were analysed separately (Figure 1), as were the spectra of plant area-types found only in the clear-cut areas, only in the old-growth forest, and plant species occurring in both the clear-cut areas and the old-growth forest (Figure 2).

In the studied stands, species from the Central European (CE) and Holarctic (HOL) area-types have a higher relative share in the old-growth forests compared to the clear-cut areas while no species belonging to the Eurasian Mountain (EAM) and Boreal (BOR) area-types were observed in the clear-cut areas at all. This observation suggests a shift towards a xerothermic microclimate and more pronounced impacts of summer temperature peaks in open spaces where clear-cutting occurred, leading to the absence of mesophilic and frigophilic species. Moreover, the absence of introduced adventive (ADV) species in the old-growth forest indicates its natural state and the absence of any human influences.

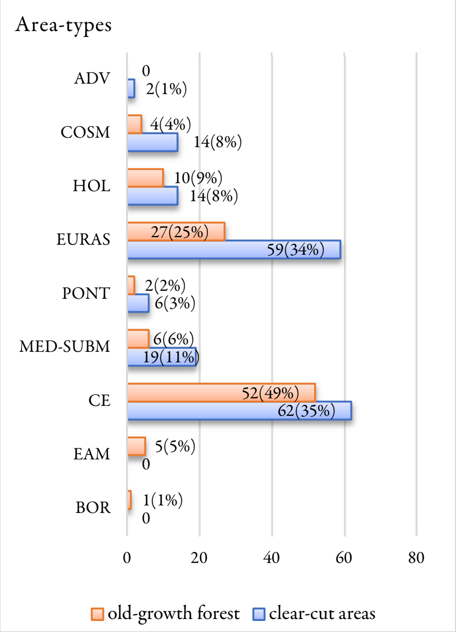

**Figure 1.** Comparative spectrum of area-types for all species identified in the clear-cut areas and the old-growth forest, expressed in the absolute number of taxa and their relative share

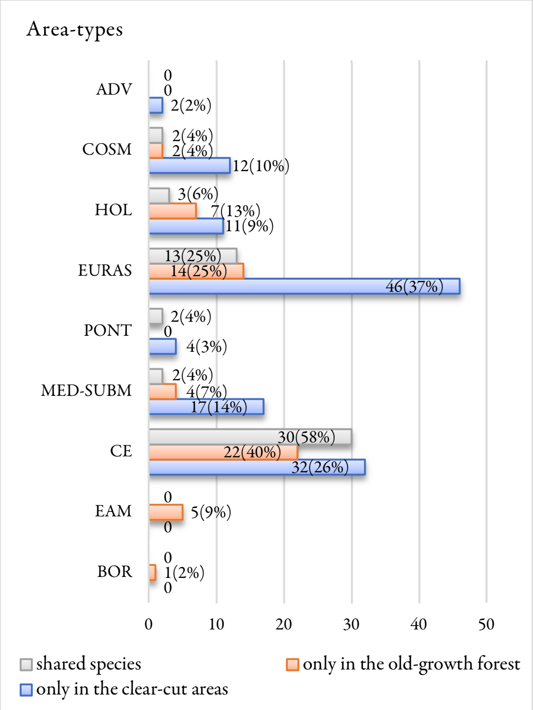

**Figure 2.** Comparative spectrum of area-types of shared and differential species in the clear-cut areas and the old-growth forest, expressed in the absolute number of taxa and their relative share

In the range spectrum of the clear-cut areas, the predominant types are the Central European area-type (CE) with 62 taxa (35%) and the Eurasian area-type (EURAS) with 58 taxa (33%). Likewise, in the range spectrum of the old-growth forest, the Central European area-type (CE) comprises 52 taxa (49%), while the Eurasian area-type (EURAS) includes 26 taxa (24%).

In practice, the notable and consistent presence of the Central European area-type (CE) in both the clear-cut areas and the old-growth forest, whose distribution centre lies in Central Europe, supports the idea that these areas represent beech forests where these plants typically occur. However, the significantly higher number of species within the Eurasian area-type (EURAS) in the clear-cut areas compared to the old-growth forest indicates a more continental climate and more pronounced microclimatic extremes in the clear-cut areas. According to research on beech forests in Central Bosnia, Sarajevo Canton (Vojniković *et al.*, 2015), Eurasian and Central European floristic elements were also found to be dominant.

The intensive colonisation of Mediterranean-submediterranean species (MED-SUBM) in the open clear-cut areas suggests a xerothermic shift in the microclimate of these areas. Similarly, there is a higher prevalence of the Pontic area-type (PONT) species in the clear-cut areas. The increased human impact, resulting in the expansion of secondary vegetation types at the expense of potential forest and shrub habitat types, contributes to the greater abundance of taxa belonging to the Pontic area-type (PONT), which specifically favour these habitat types (Zlatković, 2011).

The higher number of Cosmopolitan (COSM) species and individual occurrence of adventive species (ADV) in areas subjected to clear-cutting also indicate human impacts and the ecosystem's susceptibility to various ecological influences.

Within the Eurasian (EURAS), Mediterranean-submediterranean (MED-SUBM), and Cosmopolitan (COSM) area-types, there is a significant number of species found in the clear-cut areas but absent in the old-growth forest. Meanwhile, the highest relative share of common species found in both the clear-cut areas and the old-growth forest is within the Central European area-type (CE) (Figure 2). This suggests that taxa of the CE area-type define the beech sites of European forests in both undisturbed and disturbed ecosystems.

Conversely, taxa of EURAS, MED-SUBM, and COSM determine the openness of ecosystems in the clear-cut areas, characterised by altered ecological conditions towards a more pronounced expression of continental climate, frequent climate extremes, and xerothermic site conditions. This was confirmed by the multinomial correspondence analysis which will be discussed later.

According to Dzwonko *et al.* (2000), the floristic composition of the Balkan Peninsula shows a gradient from north to south. The proportion of Balkan, sub-Mediterranean, and Mediterranean species increases, while the proportion of Central European, European, Euro-Siberian, Eurasian, and circumpolar species decreases. This syntaxonomic differentiation of beech forests aligns with this gradient. These shifts are associated with changes in climatic conditions and the historical development of forest flora. Consequently, the biodiversity of the Balkan flora is significantly higher than that of Central European beech forests, leading to a pronounced geofloristic differentiation.

The studied area in Serbia still retains a high proportion of Central European and Eurasian floristic elements, although there is also a significant influx of sub-Mediterranean and Mediterranean species.

### *Plant life forms*

Plant life forms encompass a complex set of morphological, anatomical, physiological, and phenological adaptive characteristics in plants. Consequently, a plant's adaptive form is tuned to specific environmental conditions (Stevanović *et al.,* 2001), serving as a morphological adaptation to unfavourable climatic conditions. The biological spectrum of flora within a specific area indicates the intricate relationship between plant life forms and the ecological, primarily climatic and edaphic, factors of the region (Brković, 2015). As such, they serve as indicators, highlighting changes in these ecological conditions (particularly microclimatic), which are the focus of our research. In sufficiently warm and moist environments, tall trees with crowns and exposed buds thrive high above the ground. As environmental conditions deteriorate, trees get smaller, eventually disappearing entirely in cold and arid climates, giving way to shrubs and subshrubs. Further degradation of climatic conditions leads to the complete disappearance of woody species, leaving only herbaceous plants. Consequently, life forms are an ecological category. In other words, species that are phylogenetically related can have different life forms (Stevanović *et al*., 2001).

Raunkier (1934) defined five basic types of plant life forms based on the position of plant organs that survive during unfavourable (cold and dry) periods of the year. They are phanerophytes (P), chamaephytes (Ch), hemicryptophytes (H), cryptophytes - (C) (geophytes (G)) and therophytes (T). Each basic group of plant life forms contains subgroups mostly based on their size and habit (Table 2).

Figure 3 provides a comparative spectrum of basic life (biological) forms of plants present within the clear-cut areas and the "Vinatovača" old-growth forest, aiming to illustrate the deviation of a highly disturbed from an absolutely undisturbed, old-growth beech forest ecosystem. It presents the absolute number of species per life form with an indication of their relative share. Since the total number of species in the old-growth forest is significantly lower (176:107), the relative ratios are more balanced, except for geophytes (27% of the total plant species in the old-growth forest are geophytes, while in the clear-cut areas, only 6% belong to the group of geophytes).

Besides the species shared between the clear-cut areas and the old-growth forest, certain life forms are found only in the clear-cut areas, while they are absent in the old-growth forest. Conversely, specific species occur solely in the old-growth forest, with no presence in the clear-cut areas (Figure 4). The comparative spectra of all species in both the clear-cut areas and the old-growth forest, along with shared and differential species, are detailed in the analysis of each life form.

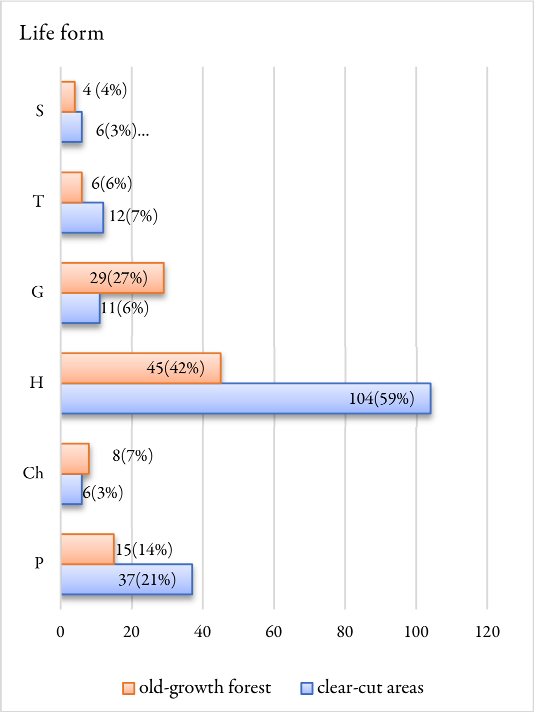

**Figure 3.** Comparative spectrum of life forms for all species identified in the clear-cut areas and the old-growth forest, expressed in the absolute number of taxa and their relative share

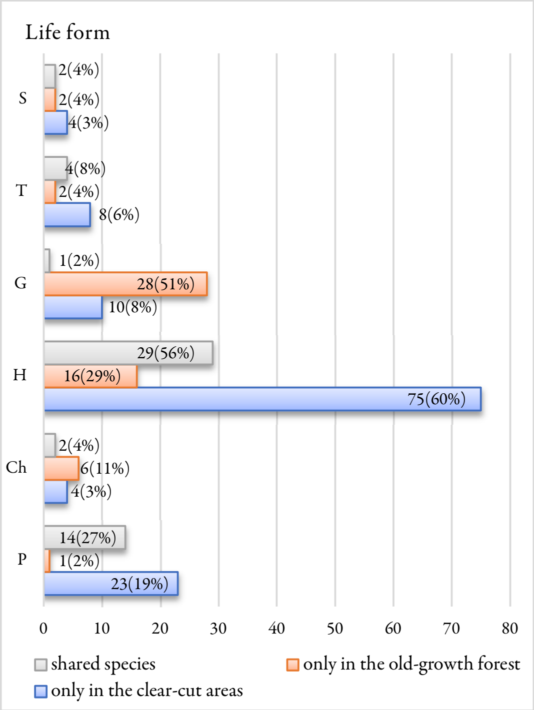

**Figure 4.** Comparative spectrum of life forms of shared and differential species in the clear-cut areas and the old-growth forest, expressed in the absolute number of taxa and their relative share

*Life form of herbaceous plants: Hemicryptophytes (H)*

As depicted in Figure 1, hemicryptophytes (H) are absolutely dominant in both disturbed and undisturbed ecosystems. However, within the disturbed ecosystem (clear-cut areas), there are 2.3 times more hemicryptophytes than in the old-growth forest. These are perennial plants whose above-ground parts die down during adverse climatic conditions, while buds from which new shoots will develop the following year persist at the base of the stem, either at or just beneath the soil surface. Hemicryptophytes thrive in the temperate climate zone and represent the predominant flora of Serbia. Hemicryptophytes account for 46.8% of the total number of species in the vascular flora of Serbia (Zlatković, 2011). In the study areas subjected to clear-cutting, hemicryptophytes constitute 59% of the total number of recorded species, whereas in beech forests, they comprise 42%. These values suggest that spontaneous flora in the clear-cut areas exhibits a more pronounced hemicryptophytic nature. The increased presence of hemicryptophytes in the clear-cut areas indicates both the continental climate of eastern Serbia and the harsher microclimate within these areas. Their share increases with altitude. Conversely, the old-growth forest, being an undisturbed ecosystem, moderates local climatic extremes, resulting in a comparatively lower occurrence of hemicryptophytes compared to Serbia's overall flora.

Out of 104 hemicryptophytes in the clear-cut areas, 75 species are exclusive to these areas and are not found in the old-growth forest. Conversely, out of 45 species found in the old-growth forest, 16 species occur solely there and are absent in the clear-cut areas. There are 29 species common to both the clear-cut areas and the old-growth forest. This observation confirms the previous thesis regarding the more pronounced microclimatic extremes in disturbed and deforested ecosystems indicated by hemicryptophytic plant species.

All hemicryptophytes are herbaceous perennials or biennials. Given their abundance, they are further classified according to their habit into subgroups (Figure 5). Accordingly, their habit can be in the form of erect stems without rosettes (H scap) – (*Cirsium arvense* (L.) Scop., *Artemisia vulgaris* L., *Hypericum perforatum* L., *Epilobium angustifolium* L., *Clinopodium vulgare* L., *Geum urbanum* L., *Atropa bella-donna* L., *Urtica dioica* L., *Scrophularia nodosa* L., *Veronica chamaedrys* L., *Salvia glutinosa* L., *Stachys germanica* L., *Cardamine bulbifera* (L.), *Achillea millefolium* L., etc.; sod (tussock-forming) (H caesp) – (*Brachypodium sylvaticum* (Huds.) P.Beauv., *Dactylis glomerata* L., *Festuca drymeja* Mert. & W.D.J.Koch, *Poa nemoralis* L., *Anthyllis vulneraria* L. etc.; semi-rosettes (H semiros) – (*Sanicula europaea* L., *Lychnis coronaria* (L.) Desr., *Viola canina* L., *Rorippa pyrenaica* (All.) Rchb.); rosettes (H ros) – (*Digitalis ferruginea* L., *Sanguisorba minor* Scop., *Aremonia agrimonoides* (L.) DC., *Taraxacum officinale* Weber v-aut, etc. or prostrate plants (H rept) – (*Fragaria vesca* L., *Veronica officinalis* L., *Astragalus glycyphyllos* L., *Ajuga reptans* L., etc.).

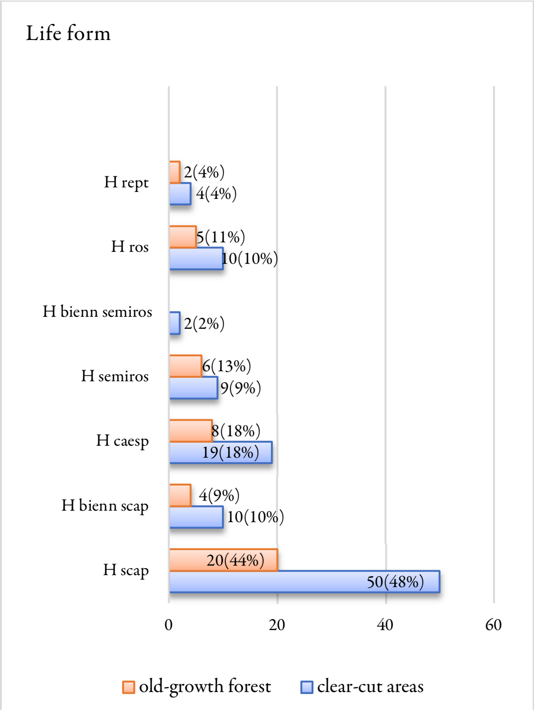

**Figure 5.** Comparative spectrum of Hemicryptophytes subgroups for all species identified in the clear-cut areas and the old-growth forest, expressed in the absolute number of taxa and their relative share

As depicted in Figure 5, it is evident that all subgroups of hemicryptophytes exhibit a higher abundance in the clear-cut areas compared to the old-growth forest. However, due to the considerably lower species count in the old-growth forest, the relative difference is notably smaller. Among hemicryptophytes, species with erect stems without rosettes (H scap) predominate. There are 2.5 times more of these species in the clear-cut areas than in the old-growth forest. The next most significant are caespitose hemicryptophytes (H caesp), which predominantly belong to the grass family (*Poaceae*). Due to weed growth, there are twice as many of them in the clear-cut areas compared to the old-growth forest.

The further differentiation of hemicryptophytes based on the habit of shared and differential species in the clear-cut areas and the old-growth forest (Figure 6) exhibits a distribution similar to the spectrum of the total number of hemicryptophytes in the clear-cut areas and the old-growth forest (Figure 7). Specifically, out of a total of 60 hemicryptophytes with erect stems without rosettes (H scap) found in the clear-cut areas and 24 species in the old-growth forest (perennial and biennial), a total of 42 species not found in the old-growth forest were recorded in the clear-cut areas (*Agrimonia eupatoria* L., *Euphorbia cyparissias* L., *Galium mollugo* L., *Lathyrus pratensis* L., *Potentilla argentea* L., *Rumex acetosella* L., *Valeriana officinalis* L., *Calamagrostis epigejos* (L.) Roth, *Dactylis glomerata* L., *Phleum pratense* L., *Turritis glabra* L., *Daucus carota* L., and others). On the other hand, seven species from this subgroup were recorded in the old-growth forest but not in the clear-cut areas (*Circaea lutetiana* L., *Epilobium montanum* L., *Lathyrus vernus* (L.) Bernh., *Parietaria officinalis* L. and others). There are 17 shared species found in the clear-cut areas and the old-growth forest (perennial and biennial) – (*Galium sylvaticum* L., *Lamium galeobdolon* (L.) L., *Mercurialis perennis* L., *Pulmonaria officinalis* L., *Geranium robertianum* L., *Pseudoturritis turrita* (L.) and others). This indicates the general dominance of hemicryptophytes with erect stems compared to other subgroups of hemicryptophytes, as also shown by the results of the multinomial correspondence analysis.

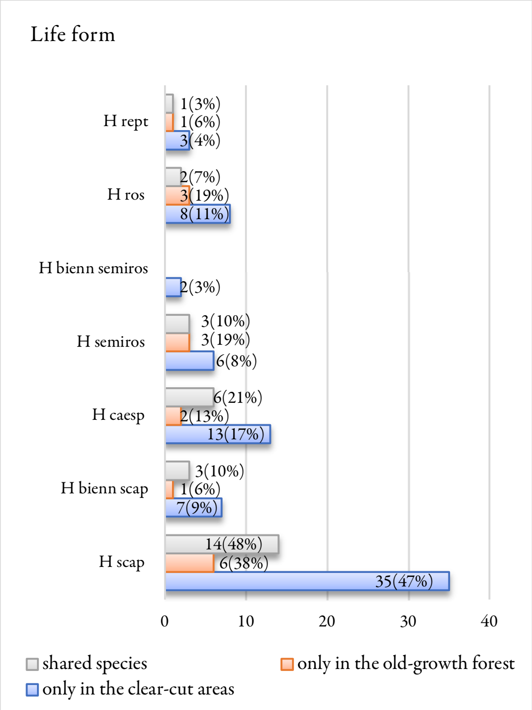

**Figure 6.** Comparative spectrum of Hemicryptophytes of shared and differential species in the clear-cut areas and the old-growth forest, expressed in the absolute number of taxa and their relative share

*Life form of woody plants: Phanerophytes* (P)

Given that the focus and aim of this research is the potential natural regeneration of forests devastated by a extreme weather disaster through vegetation succession, the abundance of species falling under the life form of phanerophytes with their classification into subgroups is of the highest importance. It is within the life form of phanerophytes that we find ecologically and economically significant tree species, holding promise for natural forest regeneration. Fischer *et al* ., (2002) in a study on the dynamics of vegetation in Central European, state that on plots with intensive disturbance of the soil surface, the composition of species changed towards the vegetation of pioneer plants, while in stands, where disturbance of the soil surface was limited, the participation of terminal tree species increased. However, within a century, the floristic structure in both cases becomes quite similar. Human activity is the key to the direction of succession of vegetation over a long period of time in terms of the relationship between pioneering and more economically valuable tree species. Our results indicate that a higher share of pioneer tree species is found where there were artificially raised stands of conifers in the beech habitat and where the surface was cleaned using mechanization, whereby the surface layer of the soil was removed. Within our climatic zone, phanerophytes predominantly include woody plants, either deciduous or evergreen. In our temperate climate zone and within the scope of this study, deciduous phanerophytes stand out as characteristic and therefore interesting.

Figure 3 reveals that phanerophytes rank second in prevalence within the clear-cut areas, following hemicryptophytes. Their number in the clear-cut areas is 2.5 times greater than in the old-growth forest. Out of the 37 phanerophyte species identified in the clear-cut areas, 23 species occur solely in these areas and are absent in the old-growth forest. Conversely, out of the 15 phanerophytes discovered in the old-growth forest, only one species is exclusive to this site and is absent in the clear-cut areas. There are 14 species found in both the clear-cut areas and the old-growth forest.

Not all phanerophytes hold equal significance in the natural regeneration of clear-cut stands. Therefore, their further division into subgroups based on height and habit shape was analysed (Figure 7). Classification based on tree height delineates three categories: tall trees ranging from 5 to 50 meters (MesP); low trees and tall shrubs attaining 2 to 5 meters in height (MiP); and low shrubs reaching up to 2 meters in height (NP). Based on the habit, phanerophytes are further classified into three groups: those with an erect stem (P scap), shrub phanerophytes (P caesp), and prostrate phanerophytes (P rept). Figure 9 displays the combinations of these phanerophyte attributes.

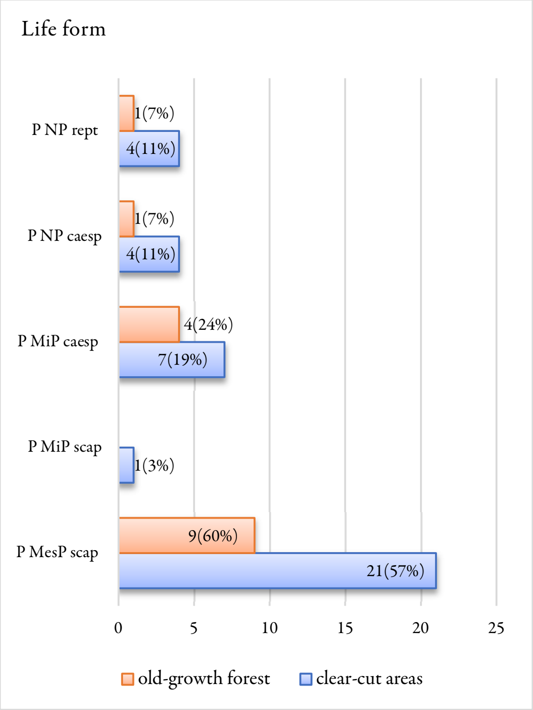

**Figure 7.** Comparative spectrum of the Phanerophytes subgroup for all species identified in the clear-cut areas and the old-growth forest, expressed in the absolute number of taxa and their relative share

The above figure clearly illustrates that the clear-cut areas harbour a greater diversity of species across all phanerophyte subgroups. In relative terms, due to the notably lower species count in old-growth forests, these proportions remain relatively consistent. Even the share of trees and tall shrubs relative to the total number of phanerophytes is slightly higher in old-growth forests. Tall trees (P MesP scap) dominate among phanerophytes. This group encompasses forest tree species such as *Fagus sylvatica* L., *Acer pseudoplatanus* L., *Prunus avium* (L.) L., *Fraxinus excelsior* L., *Quercus petraea* (Matt.) Liebl., *Corylus colurna* L., *Carpinus betulus* L., *Tilia tomentosa* Moench, *Pyrus pyraster* (L.) Burgsd., *Sorbus torminalis* (L.) Crantz., *Ulmus minor* Mill., *Juglans regia* L., etc. Their abundance is 2.3 times higher in the clearcuts compared to the old-growth forest. Notably, the old-growth forest is a monodominant beech forest (*Helleboro odori-Fagetum moesiacae* Soo & Borhidi 1960), whereas clearcuts exhibit altered microclimatic conditions, facilitating the colonisation of xerothermic species alongside beech. Heinrichs *et al*. (2013) in a study on the influence of wind and ice on vegetation successions in submontane-suboceanic beech forests in Lower Saxony and North Rhine-Westphalia, he points out that the pronounced mixture of woody species at the beginning of the succession is only temporary, because the competitive ability of beech increases with age. Especially in acidic habitats. Following forest trees in terms of species number are forest shrub species with heights of 2-5 m (P MiP caesp), such as *Crataegus monogyna* Jacq., *Sambucus nigra* L., *Corylus avellana*, *Cornus sanguinea* L., *Syringa vulgaris* L., *Viburnum lantana* L. and others). Clear-cut areas also display a higher abundance of low shrub phanerophytes up to 2 m in height (P NP caesp), including *Rosa canina L., Euonymus europaeus L., Prunus spinosa L.*, among others, as well as prostrate woody species (P NP rept), such as *Rubus hirtus* Waldst. & Kit.

and *Rubus idaeus* L. compared to old-growth forests. These shrub and prostrate species have the potential to impede natural forest regeneration, thus they are considered weed species from a forestry perspective.

The distribution of phanerophytes according to the habit of shared and differential species in the clearcuts and old-growth forests is illustrated in Figure 10. Among the 21 tree phanerophytes (P MesP scap) identified, 13 species are exclusively recorded in the clearcuts, not in the old-growth forest. Conversely, only one species from this subgroup is found solely in the old-growth forest, not in the clearcuts. Eight species are common to both the clearcuts and the old-growth forest. In the category of low trees (P MiP scap), only one species was observed, and it is exclusive to the clearcuts. Across other phanerophyte categories, clearcuts consistently host more species compared to the old-growth forest, with no species occurring only in the old-growth forest and not recorded in the clearcuts (Figure 8). Multinomial correspondence analysis results further highlight a stronger association of phanerophytes with clearcuts over the old-growth forest.

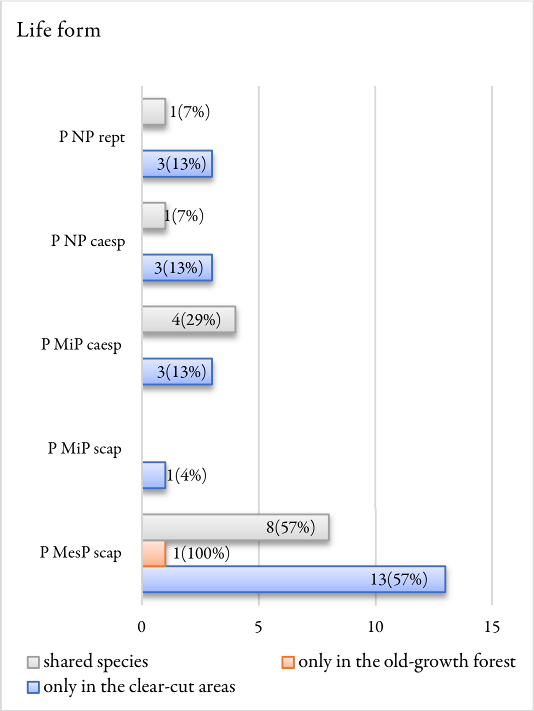

**Figure 8.** Comparative spectrum of Phanerophytes of shared and differential species in the clear-cut areas and the old-growth forest, expressed in the absolute number of taxa and their relative share

### *Life form of Geophytes (G)*

Beech forests are well-known for their communities characterised by an increased presence of geophytes in their floristic composition. These are plants that typically emerge early in spring before trees have fully leafed out; their above-ground parts quickly die down, while the plants survive in the form of underground structures, such as bulbs – G bulb, tubers – G tub, or rhizomes – G rhiz. Some geophytes develop in autumn after the leaf fall. Of all life forms, the old-growth forest is significantly richer only in geophytes compared to the clearcuts (29:11) (Figure 3). With the degradation of beech forests in the clearcuts, many geophytes have vanished. Geophytes in the form of rhizomes (G rhiz) are the most numerous (Figure 9). They include *Dryopteris filix-mas* (L.) Schott., *Pteridium aquilinum* (L.) Kuhn., *Sambucus ebulus* L., *Trifolium medium* L., *Helleborus odorus* Waldst. & Kit. ex Willd., *Carex pendula* Huds., *Elymus repens* (L.) Gould., *Polygonatum multiflorum* (L.) All. and others.

Out of the 20 species in the old-growth forest, only one is found in the clearcuts. Out of the 10 species in the clearcuts, nine species are absent in old-growth forests. Other subgroups have fewer species and are mostly characteristic of the old-growth forest (Figure 10). It should be noted that geophytes can also be parasitic plants (G par) – (*Neottia nidus-avis* (L.) L. C. M. Richard).

The association of geophytes with the old-growth forest is further illustrated by the results of multinomial correspondence analysis. Other life forms such as therophytes (T), scandentophytes (S), and hemicryptophytes (Ch) show lower presence in the surveyed beech old-growth forest and beech sites following clearcutting.

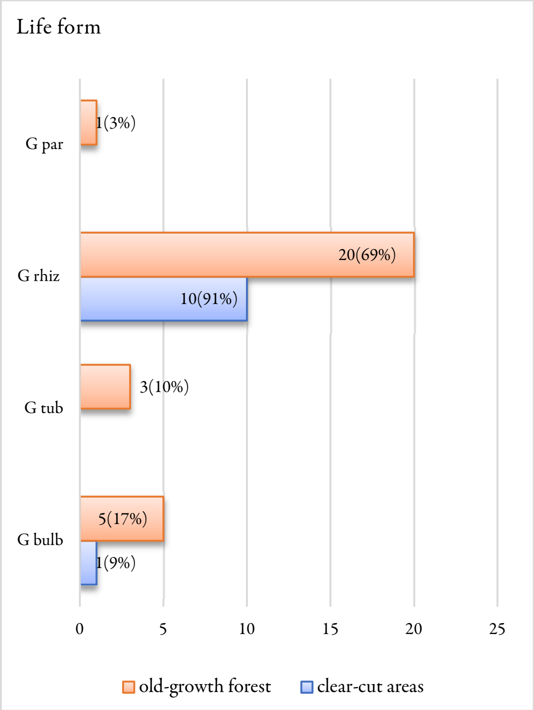

**Figure 9.** Comparative spectrum of Geophytes subgroups for all species identified in the clear-cut areas and the old-growth forest, expressed in the absolute number of taxa and their relative share

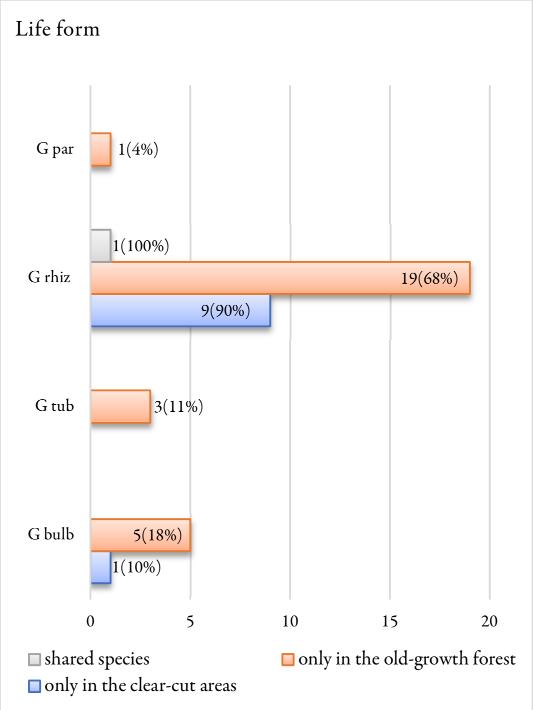

**Figure 10.** Comparative spectrum of Geophytes of shared and differential species in the clear-cut areas and the old-growth forest, expressed in the absolute number of taxa and their relative share

*Life form of annual plants: Therophytes (T)*

Therophytes are annual herbaceous plants with a short life cycle. They survive the unfavourable period of the year in the form of seeds or fruits. They thrive in southern regions, in warm climatic zones. They are characteristic of desert and Mediterranean vegetation and habitats under zooanthropogenic influences, i.e., around settlements, mines, industrial zones, pastures, and eroded areas (Stevanović *et al.,* 2001). According to Horvat (1949), therophytes are plant species that dominate in dry, hot, desert, and Mediterranean regions. They are commonly classified into subgroups based on their habit. A total of 12 species were identified in the clearcuts (Figure 3), where all except one have an erect stem form (T scap). They include *Myosotis sylvatica* Ehrh. ex Hoffm., *Lapsana communis* L., *Thlaspi arvense* L., *Linaria vulgaris* Mill., *Viola tricolor* L., *Alliaria petiolata* (M.Bieb.) Cavara & Grande and others. Only one species was found in the form of grass (T caesp) – (*Bromus sterilis L.*). In the old-growth forest, half as many species within this life form were found – a total of 6, all with an erect stem form (T scap) (Figure 11).

Out of a total of 10 species of annual therophytes with an erect stem (T scap), six species were documented in the clearcuts but were not found in the old-growth forest. Conversely, only two species from this subgroup recorded in the old-growth forest were absent in the clearcuts. Four species were commonly found in both the clearcuts and the old-growth forest. Other subgroups were exclusively found in the clearcuts (Figure 12). The presence of therophytes indicates the presence of Mediterranean-sub-Mediterranean floristic elements across all sites, which is characteristic of the climate in eastern Serbia. Their higher prevalence in clear-cut areas suggests an increased xerothermic influence on the microclimate of open spaces. Vojniković *et al.* (2015) note the absence of therophytes in all analysed beech forests in Central Bosnia, indicating a lack of significant influx from typical Mediterranean or sub-Mediterranean species.

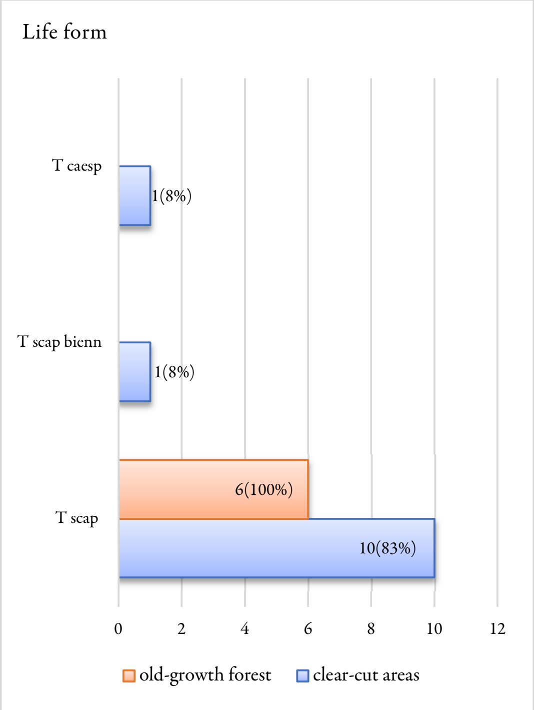

**Figure 11.** Comparative spectrum of Therophytes subgroups for all species identified in the clear-cut areas and the old-growth forest, expressed in the absolute number of taxa and their relative share

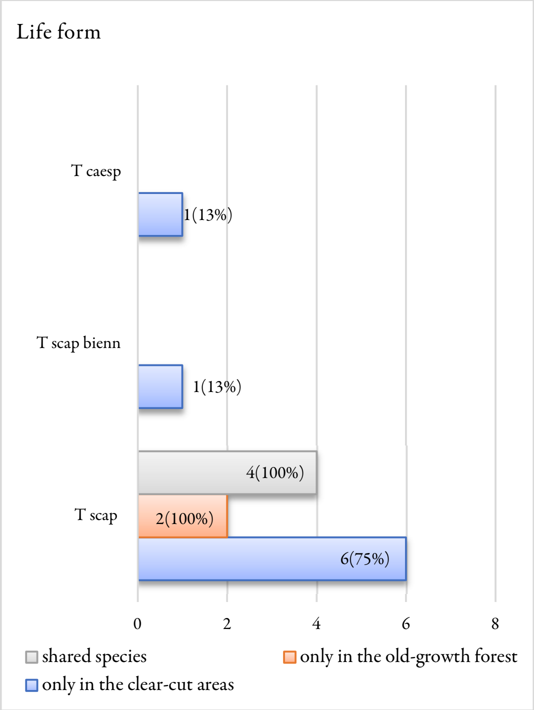

**Figure 12.** Comparative spectrum of Therophytes, of shared and differential species in the clear-cut areas and the old-growth forest, expressed in the absolute number of taxa and their relative share

### *Life form of climbers and twiners: Scandentophytes (S)*

In the clearcuts, a total of six species of scandentophytes were recorded. These include two lignified species (S lig) - *Clematis vitalba* L. and *Hedera helix* L.; two herbaceous therophytic (S T herb) - *Galium aparine* L. and *Fallopia convolvulus* (L.) Á.Löve; one herbaceous geophytic (S G herb) - *Dioscorea communis* (L.) Caddick & Wilkin; and one herbaceous hemicryptophytic (S H herb) – *Vicia cracca* L. In the old-growth forest, two species were recorded in this life form which were also found in clearcuts.

### *Life form of Chamaephytes (Ch)*

Chamaephytes are low or dwarf plants, typically growing close to the ground and reaching a height of up to 25 cm. The majority of these species are typically found in arctic or alpine environments. A total of six chamaephytes were recorded in the clear-cut areas, while eight were observed in the old-growth forest. They occur in various combinations of subforms across the surveyed areas. Plants exclusively found in the clearcuts include three species of lignified shrub chamaephytes (Ch frut caesp) and one species of prostrate herbaceous chamaephytes (Ch herb rept). Plants growing only in the old-growth forest include one species of lignified prostrate chamaephytes (Ch frut rept), one species of subshrub chamaephytes (Ch suffr), two species of herbaceous shrubs (Ch herb caesp), one species of prostrate herbaceous chamaephytes (Ch herb rept), and one species of herbaceous erect succulents (Ch herb scap succ). The chamaephytes found in both the clearcuts and the old-growth forest include one species of herbaceous shrubs (Ch herb caesp) and one species of prostrate herbaceous chamaephytes (Ch herb rept).

### *Interrelation of phytogeographical and biological characteristics of plants, ecological conditions and stand types*

To evaluate the interaction or correlation among area-types, life forms, and bedrocks across various stand types (old-growth forests (virg), clearcuts of natural beech forests (natur), and clearcuts of artificially established conifer stands within beech sites (plant), we employed a statistical method - multinomial correspondence analysis. Initially, the analysis encompassed all three stand types collectively, followed by separate assessments for areas subjected to clearcutting.

Based on the findings of the multinomial correspondence analysis across all three stand types (Figure 13), it is evident that allochthonous plants (ADV) form a distinct group with no association with any investigated stand type. Moreover, the presence of boreal (BOR) and Eurasian mountain (EAM) plants is not characteristic of the fundamental set of ecologically interconnected species. Cosmopolitan plants (COSM) are predominantly scandentophytes (S) and do not exhibit association with other plant species typical of the surveyed areas. Other area-types, life forms, and ecological characteristics related to bedrock display notable interconnectedness. Nevertheless, they can be categorised into two primary groups: plants in the old-growth forest and plants found in the clearcuts.

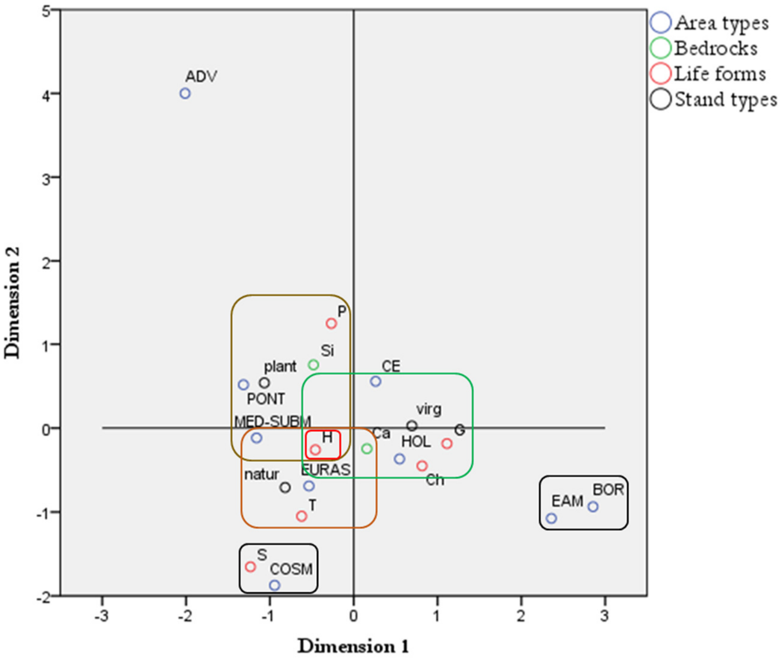

**Figure 13.** Multinomial correspondence analysis of the association of area-types (AT), life forms (LF), and bedrocks (B) for all three stand types (ST)

The plants in the old-growth forest (virg) are mainly linked to the Central European (CE) and Holarctic (HOL) area-types, along with geophytes (G) and chamaephytes (Ch) life forms, while hemicryptophytes (H) are less common. Additionally, they are typically found on limestone bedrock (Ca). The strong correlation of chamaephytes with carbonate bedrock further explains their presence in compact limestone cliffs and dissected relief, while the increased occurrence of the Central European (CE) and Holarctic (HOL) area-types explains mesophyly (Zlatković, 2011).

On the other hand, plants in the clearcuts can be further classified into two groups: plants found in areas where clearcutting of natural beech forests (natur) occurred and those in areas where clearcutting of artificially established conifer stands within beech sites (plant) took place.

Clearcuts of natural beech forests (natur) are frequently associated with Eurasian (EURAS) and partially Mediterranean-submediterranean (MED-SUBM) area-types, with primarily therophytic (T) and hemicryptophytic (H) life forms, and often found on the limestone bedrock (Ca). Conversely, areas where conifer stands were artificially established (plant) contain plants that characteristically belong to Pontic (PONT) and Mediterranean-submediterranean (MED-SUBM) area-types, predominantly hemicryptophytes (H) and phanerophytes (P) life forms, found on the silicate bedrock (Si).

Central European (CE) and Eurasian (EURAS) species dominate the research sites. However, Central European species (CE), along with Holarctic species (HOL), show a stronger affinity for old-growth forests. Conversely, Eurasian (EURAS) species, along with Mediterranean-submediterranean (MED-SUBM) and Pontic (PONT) species, are more commonly found in open areas resulting from clearcutting, as previously mentioned. Research by Zlatković (2011) in southern Serbia also supports the association of Mediterranean and Pontic taxa with the life forms of phanerophytes and therophytes. Horvat (1949) also notes the association of therophytes with the Mediterranean-sub-Mediterranean area type. Similarly, geophytes (G) and chamaephytes (Ch) are more prevalent in old-growth forests. Hemicryptophytes (H), being the most abundant plants, are distributed across all stand types, occupying a central position that overlaps all three stand types. However, they, along with therophytes (T) and phanerophytes (P), show a stronger association with open areas resulting from clearcuts.

To explore the difference in plant colonisation on clear-cut areas between natural beech forest sites (natur) and areas previously occupied by artificially established conifer stands on beech forest sites (plant), a multinomial correspondence analysis was specifically conducted for the clearcut areas (Figure 14).

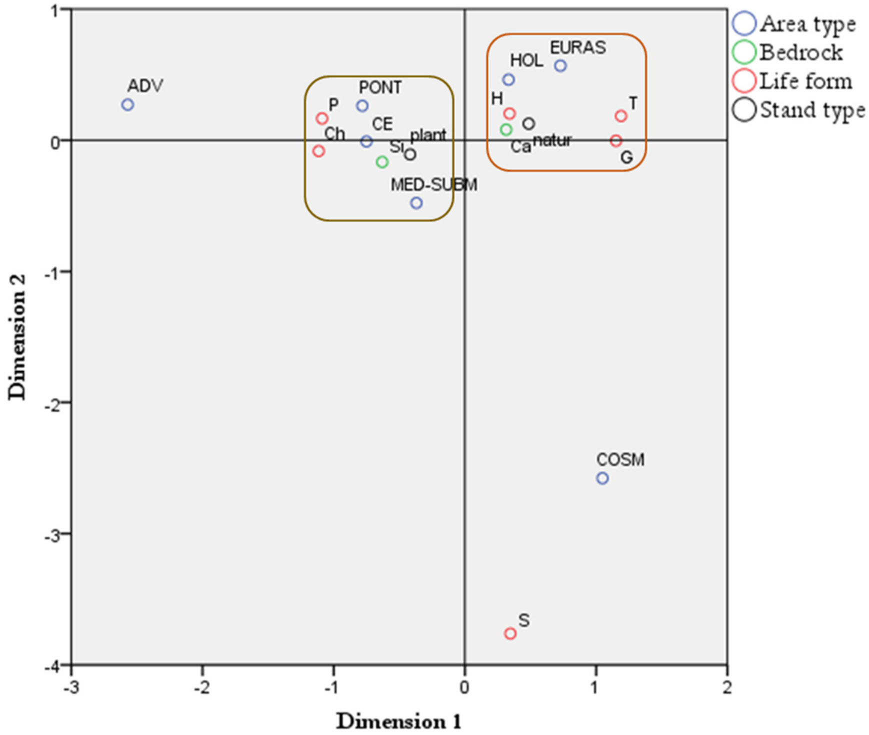

**Figure 14.** Multinomial correspondence analysis of the association of area-types (AT), life forms (LF) and bedrocks (B) on the clear-cut areas in natural beech stands and artificially established conifer stands within beech sites

Figure 14 clearly illustrates the distribution of area-types and life forms across different bedrocks within two stand types present before clearcutting (natur and plant). Similar to the previous figure, it is apparent that Eurasian (EURAS) and Holarctic (HOL) area-types are associated with barren surfaces following clearcutting within natural beech forests (natur). As depicted in Figure 13, this stand form is characterised by hemicryptophytes (H), therophytes (T), along with some geophytes (G), all of which occur over the limestone bedrock. As shown in Figure 13, all these additional ecological groups of plants (HOL, G, Ca) are positioned in the negative part of the distribution along dimension 2, as is the ecological group characteristic of clearcuts of natural beech forests, suggesting a certain association with them.

On the other hand, Figure 14 shows that the clear-cut areas of artificially established conifer stands within beech sites (plant) predominantly encompass Pontic (PONT) and Mediterranean-Submediterranean (MED-SUBM) area-types, along with some Central European area-type (CE). In Figure 13, the CE area-type occupies the positive part of dimension 2, mirroring the ecological group of plants characteristic of the stand form labelled as plant, indicating their significant association. Regarding life forms, as in Figure 13, phanerophytes and silicate bedrock are associated with this group. In the spatial graphical model, chamaephytes (Ch) have less significance due to their lower abundance. Although hemicryptophytes (H) are the most abundant plants in all cases, they are more characteristic of the areas where artificially established conifer stands within beech sites were present, as supported by previous descriptive analyses. Adventive (ADV) and Cosmopolitan (COSM) area-types, along with the scandentophytes (S) life form, are not linked to either of the two examined stand types, as confirmed by the joint analysis (Figure 13).

### *General considerations based on the study*

Based on the floristic composition and phytogeographic and biological analyses conducted in areas subjected to clear-cutting in natural beech forests and artificially established conifer stands within the beech site (*Helleboro odori-Fagetum moesiacae* Soo & Borhidi 1960), the following conclusions can be drawn:

Five years after clear-cutting, beech sites exhibited significantly richer floristic diversity compared to natural beech forests of old-growth origin. A total of 176 taxa of vascular plant species were recorded in the clear-cut areas, whereas only 107 taxa were found in the old-growth forest.

Chorological analysis of floristic composition revealed the presence of seven main area-types in the clear-cut areas, contrasting with nine in the old-growth forest. The dominant types within the range spectrum of the clear-cut areas included the Central European area-type (CE) with 62 taxa (35%) and the Eurasian area-type (EURAS) with 58 taxa (33%). This pattern is mirrored in the range spectrum of the old-growth forest, where the Central European area-type (CE) comprised 52 taxa (49%) and the Eurasian area-type (EURAS) 26 taxa (24%). These findings support the notion that these are indeed beech forests which are typically characterised by the presence of these plants. The notably higher number of species within the Eurasian area-type in the clear-cut areas compared to the old-growth forest suggests a more pronounced influence of continental climate in the clear-cut areas, leading to more pronounced microclimatic extremes.

The higher relative abundance of species within the Central European (CE) and Holarctic (HOL) area-types in the old-growth forest compared to the clear-cut areas, along with the absence of species from the Eurasian Mountain (EAM) and Boreal (BOR) area-types in the clear-cut areas, suggests a shift towards xerothermic microclimates and more pronounced impacts of summer temperature peaks in the open areas of clearcuts, resulting in the absence of mesophilic and frigophilic species.

The lack of introduced adventive species (ADV) in the old-growth forest underscores its natural state and the absence of any human impact. The intensified colonisation by Mediterranean-submediterranean (MED-SUBM), Pontic (PONT), and to a lesser extent adventive (ADV) and cosmopolitan (COSM) species in the clear-cut areas indicates a shift towards xerothermic microclimates in open spaces and increased human activity, leading to the spread of secondary vegetation types at the expense of potential forest sites.

Within the Eurasian (EURAS), Mediterranean-submediterranean (MED-SUBM), and to a lesser extent Cosmopolitan (COSM) area-types, clear-cut areas exhibited a notable presence of species absent in the old-growth forest. However, the highest relative abundance of shared species between the clear-cut areas and the old-growth forest lies within the Central European area-type (CE), indicating beech sites in both undisturbed and disturbed ecosystems. Taxa of EURAS, MED-SUBM, and COSM define the openness of ecosystems in the clear-cut areas, with altered ecological conditions towards a stronger manifestation of continental climate, marked by frequent climate extremes and xerothermic site conditions.

In both disturbed and undisturbed ecosystems, hemicryptophytes dominate, with the disturbed ecosystems, i.e. clear-cut areas (59%) harbouring 2.3 times more hemicryptophytes than the old-growth forest (42%). The hemicryptophytic nature of the investigated ecosystems denotes a temperate climatic zone, with the increased presence of hemicryptophytes in the clear-cut areas suggesting the influence of the continental climate of eastern Serbia on one hand, and even harsher microclimate in the clear-cut areas on the other hand. The old-growth forest, as a completely undisturbed ecosystem, mitigates local climatic extremes, thus having a relatively lower proportion of hemicryptophytes. Across all subgroups, clear-cut areas surpass the old-growth forest in the number of hemicryptophytes, with species lacking rosettes and having an erect stem (H scap) being particularly dominant. There are 2.5 times more of these species in the clear-cut areas than in the old-growth forest. Out of a total of 104 hemicryptophytes in the clear-cut areas, 75 species are exclusive to these areas and absent in the old-growth forest, while out of 45 species found in the old-growth forest, 16 are exclusive to it and absent in the clear-cut areas. A total of 29 species are common to both the clear-cut areas and the old-growth forest.

The presence of phanerophytes in the clear-cut areas exceeds that in the old-growth forest by 2.5 times. Among the 37 phanerophyte species identified in the clear-cut areas, 23 are exclusive to these areas, but absent in the old-growth forest. Conversely, out of the 15 phanerophytes found in the old-growth forest, only one species is exclusive to this site. Fourteen species are shared between the clear-cut areas and the old-growth forest. Tall trees (P MesP scap) dominate among phanerophytes, with 2.3 times more of them in the clear-cut areas compared to the old-growth forest. This increase is attributed to altered microclimatic conditions, allowing xerothermic pioneer species to colonise clear-cut areas alongside shade-tolerant beech. Of the 21 tree phanerophytes (P MesP scap) identified, 13 species grow only in the clear-cut areas, while only one species from this subgroup is found solely in the old-growth forest. Eight species are common to both the clear-cut areas and the old-growth forest.

Of all life forms, only geophytes are significantly more abundant in the old-growth forest compared to the clear-cut areas (29:11). Out of the 20 geophyte species in the old-growth forest, only one is also present in the clear-cut areas. Other life forms, including therophytes (T), scandentophytes (S), and chamaephytes (Ch), are less prevalent in the investigated beech old-forest and beech sites after clear-cutting.

The results contribute to our understanding of the pathways of forest ecosystem degradation due to extreme weather events. Previous research on this topic in Serbia has employed various approaches, most commonly focusing on vegetation succession after fires (Vukićević, 1965; Glišić, 1950). Redžić (1988) identifies specific representatives of vascular flora as indicators of site and forest phytocenosis degradation following clear-cutting. A study on spontaneous successions of vegetation (Prach *et al.*, 2001) highlights the need for interdisciplinary approaches and communication between scientists, engineers and decision makers.

## Conclusion

In conclusion, it can be noted that the old-growth forest exhibits the highest mesophilic characteristics, while xerothermophilic elements are more pronounced in deforested beech sites. Areas with artificially established conifer stands demonstrate greater xerophilic tendencies compared to natural beech sites. The increased presence of pioneer tall tree phanerophytes (P MesP scap) in the clear-cut areas suggests the potential for natural regeneration through vegetation succession over an extended period.

## Authors' Contributions (please add)

Conceptualization: BP, VČ, SS, VB, LjR. Data curation: BP, VČ, SS. Formal analysis: BP, VČ, ZP. Funding acquisition: LjR. Methodology BP, VČ. Writing - original draft: BP, VČ, SS, VB, MV. Writing - review and editing: BP, VČ, ZP.

All authors read and approved the final manuscript.

## **Ethical approval** (for researches involving animals or humans)

Not applicable.

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## Conflict of Interests

The authors declare that there are no conflicts of interest related to this article.

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