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Vegetational and Structural Features of Forest Clearings in Plitvice Lakes National Park

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ABSTRACT

The impact of various ecological factors, biogeographical position and both former and current anthropogenic activity in Plitvice Lakes National Park greatly influenced the development of different habitat types, including forest clearings. Due to the insufficient knowledge of this habitat type, based primarily on general descriptions within the National Habitat Classification of the Republic of Croatia (NN 27/2021, NN 101/2022), this paper deals with presenting their vegetational and structural characteristics in the national park area. The following taxonomic keys were used to determine plant species: Tutin et al. (1964-1980), Pignatti (1982), Javorka and Csapody (1991) and Martinčič et al. (1999). Furthermore, scientific nomenclature of plant species was conducted using Flora Croatica Database (Nikolić 2012), while threat status was aligned by the Red Book of Vascular Flora of Croatia (Nikolić and Topić 2005). Also, protection level was adjusted according to the Regulation on strictly protected species (NN 144/2013, NN 73/2016). Spectrum of life forms and chorological types were aligned according to Pignatti (2005). Vegetation was studied in accordance with the principles of the Braun-Blanquet approach (Braun-Blanquet 1964). Together with the basic parameters of the selected plots, the research also included the collection of structural parameters of forest clearings according to Medak et al. (2023). Based on conducted research, a total of 98 plots of forest clearing habitats were established with a total of five different forest clearing communities. The largest number of forest clearing communities belonged to *Salicetum capreae*, followed by *Eupatorietum cannabini*, *Atropetum bella-donae*, *Telekium speciosae* and *Rubetum idaei*. A total of 257 species of vascular plants were identified in the area and classified into 60 families. The most represented family was Asteraceae, while the highest relative representation of life-forms belonged to hemicryptophytes (H). Furthermore, the most represented chorologycal type in the area was Eurasian (20.6%). The habitat type contained a total of 11 strictly protected (SZ), 6 nearly threatened (NT), 3 vulnerable (VU), 2 data-deficient (DD) and 4 endemic species. In addition, the largest number of plots had an anthropogenic origin, irregular type (shape), occupied a small area (less than 1000 m^2) and were located along the edges of both forests and forest roads. The results of this paper represent the first vegetational and structural data of forest clearings in the national park area which contribute to an expansion of our knowledge and understanding of this habitat type, and form a starting point for the necessary future research.

Keywords: Croatia; flora; forest clearing typology; phytosociology

INTRODUCTION

Plitvice Lakes is the oldest and the largest national park in the Republic of Croatia. It is situated on the border of Lika, Kordunska plain and the Ogulin-Plaščan valley and between Mala Kapela mountain range in the west and northwest, and Lička Plješivica in southeast. The area of the national park covers 29,630 ha in total and contains 20 inhabited areas.

As a part of the Dinaric karst region at an altitude between 369 and 1279 meters, it represents one of the most impressive worlds' karst landscapes marked by specific geological, geomorphological and hydrological features. With approximately 25,000 ha (81% surface of the park) of beech and beech-fir forests, it belongs to the most forested parts of the Republic of Croatia. According to the Plitvice Lakes National Park management plan 2019-2028, the rest is covered by non-forested areas classified as grasslands (15%) and water surfaces (1%). Only 3% of the area has been significantly modified by anthropogenic activity.

In terms of flora and vegetation, the area has been very well researched, followed by numerous research of both forest (Vukotinović-Farkas 1859, Schlosser and Vukotinović

Figure 1. Spatial position of Plitvice Lakes National Park (Source: Plitvice Lakes National Park management plan 2019-2028).

1869, Hirc 1877, Hirc 1900, 1908, Horvat 1958, Trinajstić 1970, 1972, Plavšić-Gojković et al. 1972, Prpić 1972, 1979, Cestar et al. 1974, Plavšić-Gojković et al. 1974, Cestar et al. 1976, Pelcer 1976, Krga 1992, Pavlović 2012, Jozić 2013, Mihaljević 2013, Vukelić and Šapić 2013, Martinić 2019, Vukelić et al. 2019, 2023, Baneković 2020,) and non-forest habitats (Vukotinović-Farkas 1859, Schlosser and Vukotinović 1869, Hirc 1877, Hirc 1900, 1908, Pavletić 1957, Matoničkin and Pavletić 1963, Gaži-Baskova et al. 1982, Šegulja and Krga 1988, 1989, 1990a, 1990b, 1990c, 1990d, 1990e, 1990/1991, Krga 1992, Šegulja 1992, 2000, 2005, Šegulja and Hršak 1994, 1995, Kranjčev 2003, Špoljarić and Belančić 2007, Stančić et al. 2010, Alegro et al. 2014, 2019, Hudina and Katanović 2016). On the contrary, studies on the non-forest habitat types such as forest clearings, have not been conducted. As an indispensable part of developing stable forest complexes, forest clearings are characterized by structural uniqueness, specific flora composition and constant variability (Busing and White 1997, White and Pickett 1985, Runkle 1989, Fahey and Puettmann 2007, Schliemann and Bockheim 2011, Lanta et al. 2019). According to the Annex 1 of the Regulation on the list of habitat types and habitat maps (National Habitat Classification of the Republic of Croatia, NHC) in the Republic of Croatia, forest clearings (C.5.2.) consist of tall herbaceous perennial plant species (1-3 m), followed by taller or shorter development of the shrub layer and, sometimes, by juvenile forms of low trees. Plant species mostly belong to Apiaceae, Asteraceae, Ranunculaceae and Liliaceae families. Currently valid division of habitat types of forest clearings (C.5.2.) in the Republic of Croatia is presented in Table 1.

In addition to an increased share of the herb layer, forest clearings also participate in dynamics of developing both shrub and tree layer and thus enable the formation of heterogeneous vegetation units (Runkle 1989, Lanta et al. 2019). It is also important to mention the influence of habitat on the development of numerous endangered plant species (Lanta et al. 2019).

Apart from differences in vegetation formations, forest clearings also differ in structural characteristics recently presented and consolidated in a review paper by Medak et al. (2023), where their structural categorization was established regarding their origin, type (shape), size and location (Table 2).

Current scheme of C.5.2. forest clearings habitat type presented in the National Habitat Classification of the Republic of Croatia as well as the unexplored structural

Table 1. Forest clearings classification in Croatia (Source: NN 27/2021, NN 101/2022).

National Habitat Classification of the Republic of Croatia (NHC) - levels, codes and names				
I	**II**	**III**	**IV**	**V**
C. Lawns, bogs and tall greens	C.5. Tall greens	C.5.2. Forest clearings	C.5.2.1. Belladona and blooming sally forest clearings C.5.2.2. Forest clearings, forest road edges (NHC 1-4: C.5.2.1.3.)	C.5.2.1.1. Belladona and blooming sally community (*Atropetum bella-donae* Br.-Bl. 1930) C.5.2.1.4. *Telekia speciosa* community (*Telekium speciosae* Treg. 1941)

Table 2. Forest clearing typology (Medak et al. 2023).

Forest Clearing Typology		
Origin	Natural	Anthropogenic
Type (Shape)	Irregular	Regular
Size	Small (<1000 m^2)	Large (>1000 m^2)
Location	Forest Interior	Forest Edge

characteristics, point out the insufficient research of habitat types in our area. The aim of this paper is to present current flora and vegetation of forest clearings as well as its structural features in the national park area, which will increase the knowledge about this habitat type.

MATERIALS AND METHODS

In order to research floristic and structural features of forest clearings in the national park area, both preparatory work and data sampling were conducted.

Preparatory Work – Vegetation Parameters of Forest Clearings

The most important indicator for identification of the habitat type is flora composition. With the aim of selecting locations for the field research, the relevant literature related to the forest clearing vegetation was studied. This included all available and applicable data of flora composition, ecological characteristics, systematics, and typology of forest clearings. Considering the insufficient knowledge of such habitat types in our area, based primarily on general descriptions within the National Habitat Classification of the Republic of Croatia (NHC), for more detailed and broader description, the appropriate attached literature from Austria (Wallnöfer 1993, Willner and Grabherr 2007), the Czech Republic (Chytrý et al. 2010, Chytrý 2013) and Poland (Matuszkiewicz 2001) was studied. In addition to the habitat types of forest clearings already presented within the NHC, the following potential habitat type communities in our area were included: *Atropetum bella-donnae* Br.-Bl. 1930, *Eupatorietum cannabini* Tx. 1937, *Senecioni-Epilobietum angustifolii* Hueck 1931, *Senecioni fuchsii-Sambucetum racemosae* Noirfalise ex Oberdorfer 1957, *Rubetum idaei* Kaiser 1926 and *Salicetum capreae* Schreier 1955.

Data Sampling

After preparatory work, this phase of research included field work during growing seasons from September 2020 until August 2021. The locations of established habitat types were recorded with GARMIN GPSmap 62s GPS receiver. The following taxonomic keys were used to determine plant species: Tutin et al. (1964-1980), Pignatti (1982), Javorka and Csapody (1991) and Martinčič et al. (1999).

Furthermore, scientific nomenclature of plant species was conducted using Flora Croatica Database (Nikolić 2012), while threat status was aligned by the Red Book of Vascular Flora of Croatia (Nikolić and Topić 2005). Also, protection level was adjusted to the Regulation on strictly protected species (NN 144/2013, NN 73/2016). The spectrum of life forms as well as chorological types were aligned according to Pignatti (2005).

In order to determine affiliation to the potential associations, both characteristic and diagnostic species, i.e. main and dominant species on the plots, were recorded. The criteria for including a certain locality in forest clearing habitat type was the presence of one or more diagnostic species on at least 50% of the surface. Vegetation was studied in accordance with the principles of the Braun-Blanquet approach (Braun-Blanquet 1964). Together with the basic parameters of selected plots such as its number, coordinates and altitude, the research also included the collection of structural parameters of forest clearings according to Medak et al. (2023).

Based on the conducted preparatory work and data sampling, a total of 98 plots of forest clearing habitats were established (Figure 2), mostly located on the western and northwestern part of Plitvice Lakes National Park.

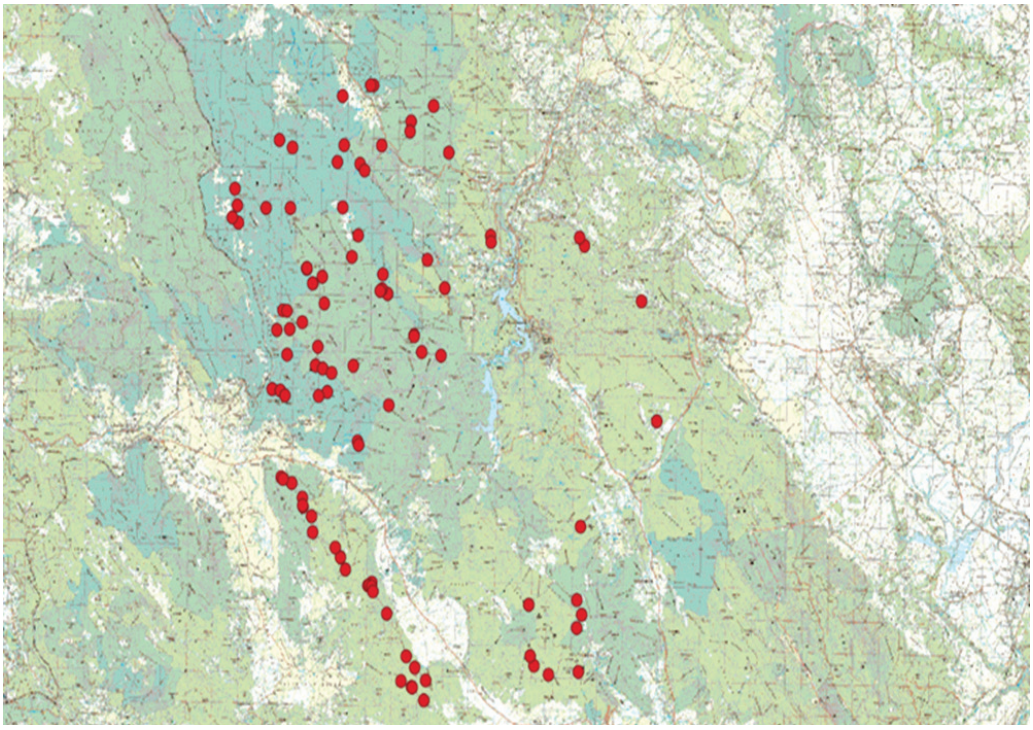

Figure 2. Location of all areas belonging to C.5.2. forest clearings habitat type in Plitvice Lakes National Park.

RESULTS

Forest Clearing Flora

According to the research, a total of 257 species of vascular plants classified into 60 families were identified in the forest clearing area. The most represented family included Asteraceae with 26 taxa (10.1%), followed by Rosaceae with 24 taxa (9.3%), Lamiaceae family with 20 taxa (7.8%), Poaceae with 15 (5.8%) and Apiaceae with 13 taxa (5.0%). A relatively large share of species belonged to Ranunculaceae and Brassicaceae with 10 taxa (3.9%) in total. The total number of species per family and the percentage share of families represented by more than 1% is visible in Figure 3.

Families with a share of less than 1% included: Woodsiacae, Violaceae, Valerianaceae, Urticaceae, Ulmaceae, Tymelaceae, Tiliaceae, Staphyleaceae, Solanaceae, Scrophulariaceae, Salicaceae, Rubiaceae, Rosaceae, Rhamnaceae, Ranunculaceae, Pyrolaceae, Primulaceae, Polygonaceae, Poaceae, Plantaginaceae, Pinaceae, Oxalidaceae, Orchidaceae, Onagraceae, Oleaceae, Melanthiaceae, Liliaceae, Lamiaceae, Juncaceae, Hypolepidaceae, Geraniaceae, Gentianaceae, Fagaceae, Fabaceae, Euphorbiaceae, Equisetaceae, Dryopteridaceae, Dipsacaceae, Dioscoreaceae, Cyperaceae, Cupressiaceae, Corylaceae, Cornaceae, Convolvulaceae, Clusiaceae, Cichoriaceae, Caryophyllaceae, Caprifoliaceae, Campanulaceae, Brassicaceae, Boraginaceae, Balsaminaceae, Asteraceae, Aspleniaceae, Asparagaceae, Asclepiadaceae, Aristolochiaceae, Araliaceae, Apiaceae and Amaryllidaceae.

The most represented chorologycal type in the area was Eurasian (20.6%), followed by Euro-Caucasian (12.9%), paleotemporal (12.5%) and S-E-SE-European (10.6%). Circumboreal (9.8%), Euro-Siberian (6.7%), Centro-European (5.1%), European (5.1%), Euro-Mediterranean (3.5%), both subcosmopolitan and cosmopolitan (3.1%), S-European-Sub-Siberian (3.1%) as well as Subatlantic, Avv. Naturalizz. and endemic/subendemic with a total of 1.2% were also present. Chorological types represented with more than 1% as well as their percentage share are visible in Figure 4. Chorological types with a share less than 1%, on the other hand, included NE-W-Mediterranean-Montane, NW-W-European (Subatlantntic) and NE-S-Stenomediterranean with a total of 0.8%. The least represented chorological types included W-Mediterranean-Montane, Pontica and European-West Asian with a total of 0.4%.

In addition (Table 3 and Figure 5), the highest relative representation of life forms in researched forest clearing habitat type belonged to hemicryptophytes (56.8%), followed by geophytes (16.0%) and phanerophytes (13.6%). The lowest relative representation, on the other hand, had therophytes (5.4%), nano-phanerophytes (3.1%) and chamephytes (2.3%).

The results also showed that in total 6 species were nearly threatened (NT), 3 vulnerable (VU) and 2 data-deficient (DD). With a total of 11 strictly protected species (SZ), according to the Regulation on strictly protected species (NN 144/2013, NN 73/2016), a total of 4 endemic species were also identified (Table 4).

Table 3. Representation of life-forms of forest clearing plant taxa (H - Hemicryptophytes, Ch - Chamephytes, P - Phanerophytes, NP - Nano-Phanerophytes, G - Geophytes, T - Therophytes).

Life form	Number of species	Species percentage (%)
H	146	56.8
Ch	6	2.3
P	42	13.6
NP	8	3.1
G	41	16.0
T	14	5.4

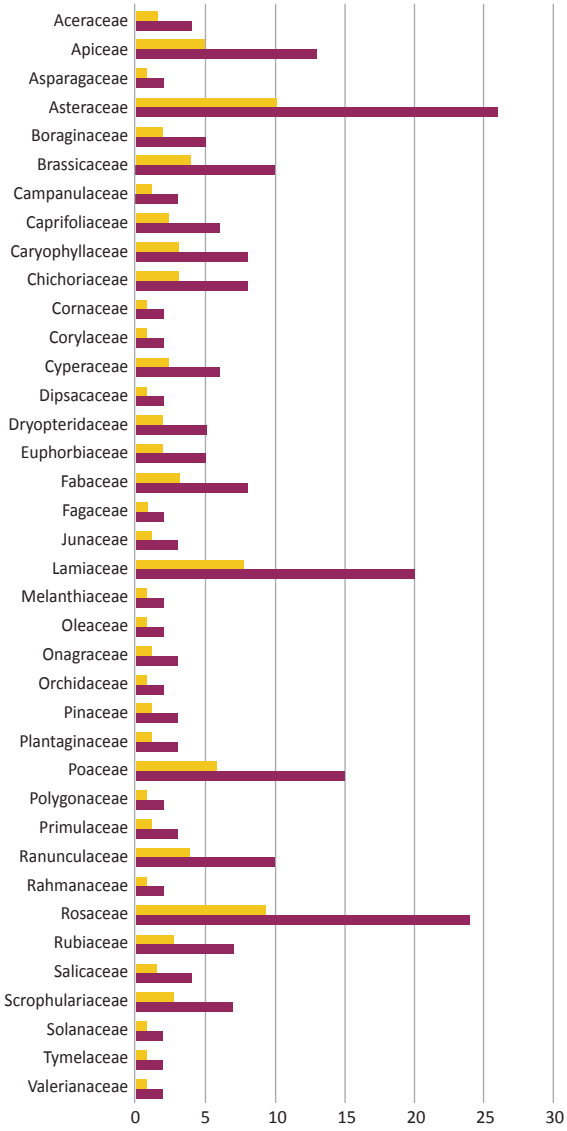

Figure 3. The total number of species per family (labeled red) and the percentage share of families (labeled yellow).

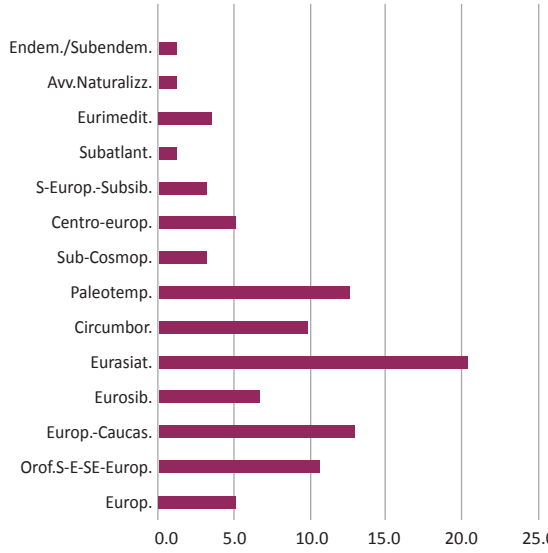

Figure 4. Spectrum of chorological types represented by more than 1%.

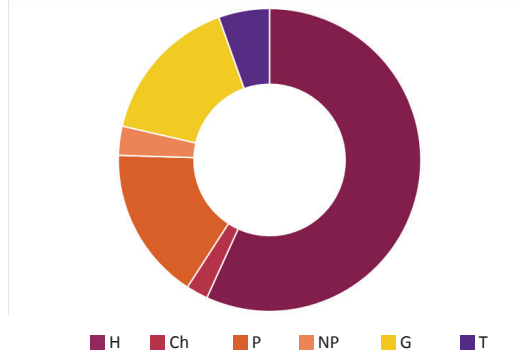

Figure 5. Taxa life-form overview (H - Hemicryptophytes, Ch - Chamephytes, P - Phanerophytes, NP - Nano-Phanerophytes, G - Geophytes, T - Therophytes).

Table 4. List of forest clearing plant taxa according to threat status (DD – data-deficient, NT - near threatened, VU - vulnerable), protection level (SZ - strictly protected) and endemic status.

Plant taxa	Threat status	Protection level	Status
Cardamine chelidonia L.	-	SZ	endemic
Cardamine kitaibelii Bech.	-	SZ	endemic
Cardamine waldsteinii Dyer	-	SZ	endemic
Cyclamen purpurascens Mill.	NT	-	-
Daphne laureola L.	NT	-	-
Daphne mezereum L.	NT	-	-
Digitalis grandiflora Mill.	NT	-	-
Gentiana asclepiadea L.	NT	-	-
Helleborus multifidus Vis.	-	SZ	endemic
Helleborus niger L.	-	SZ	-
Hepatica nobilis Schreb.	VU	-	-
Lilium martagon L.	VU	SZ	-
Neottia nidus-avis (L.) Rich.	-	SZ	-
Platanthera bifolia (L.) Rich.	VU	SZ	-
Pyrola rotundifolia L.	DD	SZ	-
Ruscus hypoglossum L.	NT	SZ	-
Veratrum album L.	DD	SZ	-

Forest Clearing Vegetation

Through fieldwork and data processing according to the described methodology, the following C.5.2. forest clearing communities were determined (Table 5).

The area is mostly covered by forest clearings, forest road edges (45.9%), followed by *Eupatorietum cannabini* community (29.6%), belladona and blooming sally community (10.2%) and *Telekium speciosae* community (10.2%). *Rubetum idaei community* (4.1%), on the other hand, is the least represented.

C.5.2.1. Belladona and blooming sally forest clearings (Aliance *Atropion* Br.-Bl. 1950, em. R. Tx. 1950, syn. *Epilobion angustifolii* Oberd. 1957)

It is a habitat type covering two communities at the fifth community level: C.5.2.1.1. (*Atropetum bella-donae*) and C.5.2.1.4. (*Telekium speciosae*). A total of 20 plots belonging to belladona and blooming sally forest clearings were identified, of which 10 belong to *Atropetum bella-donnae* and 10 to *Telekium speciosae* community. Since a certain number of localities included *Rubetum idaei* and *Eupatorietum cannabini* communities that have not yet been precisely classified, they were also synthesized at the fourth level, under the same C.5.2.1. code. A total of 33 plots belonging to the broader type of belladona and blooming sally forest clearings were identified, of which 29 belong to *Eupatorietum cannabini*, and 4 to *Rubetum idaei* community.

C.5.2.1.1. *Atropetum bella-donnae* Br.-Bl. 1930 community

Atropa bella-donna was widely distributed in Plitvice Lakes National Park, mostly along forest roads, intersections, road extensions or in the former warehouse area (Figure 6). It rarely dominated on areas above 50 m², but it was often part of forest clearing types dominated by the diagnostic species such as *Eupatorium cannabinum, Telekia speciosa* or *Salix caprea*. In addition to diagnostic species, *Salvia glutinosa, Rubus hirtus, Stellaria nemorum, Carex sylvatica, Hypericum perforatum* and other species were also common. Furthermore, the open areas beneath the former overhead transmission lines, where association was under the succession process, mostly included: *Sambucus nigra* and *Eupatorium cannabinum*, as well as *Corylus avellana, Cornus sanguinea, Dryopteris filix-mas, Clematis vitalba, Geranium robertianum, Galium odoratum, Brachypodium sylvaticum, Scrophularia nodosa, Rubus hirtus* and *Salvia glutinosa*.

C.5.2.1.4. *Telekium speciosae* community Treg. 1941

The community was located in the interior parts of Plitvice Lakes National Park forests, along forest roads and their intersections as well as in the former warehouse areas (Figure 7). Apart from *Telekia speciosa*, many other species were recorded such as: *Acer pseudoplatanus, Fagus sylvatica* and *Sambucus nigra*, *Eupatorium cannabinum, Stellaria nemorum, Fragaria vesca, Rubus hirtus, Stachys sylvatica, Brachypodium sylvaticum, Salvia glutinosa* and *Galium odoratum*. Also, the community included *Salix caprea, Geranium robertianum, Carex sylvatica, Arctium lappa, Silene dioica, Urtica dioica, Scrophularia nodosa* and *Mycelis muralis. Telekia speciosa* was also found individually and in the composition of other habitat types. It was also part of the C.5.2.2. type within dominance of *Salix caprea*, as well as *Eupatorium cannabinum*.

Table 5. Forest clearing plant communities in Plitvice Lakes National Park.

National Habitat Classification (NHC) type	Plant community	Number of plots	Plot percentage (%)
C.5.2.1.1.	Belladona and blooming sally community (*Atropetum bella-donae* Br.-Bl. 1930)	10	10.2
C.5.2.1.4.	*Telekium speciosae* community (*Telekium speciosae* Treg. 1941)	10	10.2
C.5.2.2. (NHC 1-4: C.5.2.1.3.)	*Salicetum capreae* community (*Salicetum capreae* Schreier 1955)	45	45.9
C.5.2.1.	*Eupatorietum cannabini* community (*Eupatorietum cannabini* Tx. 1937)	29	29.6
C.5.2.1.	*Rubetum idaei* community (*Rubetum idaei* Kaiser 1926)	4	4.1

Figure 6. *Atropetum bella-donnae* community at forest edge near Mačje doline.

Figure 7. *Telekium speciosae* community near the forest road between Čorkova uvala and Delićka meadow.

C.5.2.1. *Eupatorietum cannabini* Tx. 1937, clearings dominated by *Eupatorium cannabinum*

Eupatorium cannabinum was the most widespread diagnostic species in the national park. An example of its distribution was a road branch over 900 m long in Bračinovac where *E. cannabinum* completely dominated growing on both sides of the road up to 5 m in width (Figure 8). *E. cannabinum* specimens were found usually on moist,

semi-shady to sunny locations along watercourses, in meadows, on forests edges and along roads. In addition to *E. cannabinum*, species such as *Salvia glutinosa, Fragaria vesca, Brachypodium sylvaticum, Hypericum perforatum,* and *Dryopteris filix-mas* were the most common. *Acer pseudoplatanus, Fagus sylvatica, Rubus hirtus*, *Atropa bella-donna* and *Salix caprea* were also present. In wetter conditions, *E. cannabinum* predominantly developed with *Cirsium palustre, Urtica dioica, Angelica sylvestris, Deschampsia cespitosa, Succisa pratensis, Equisetum arvense* and *Lysimachia vulgaris.* In less humid conditions, on the other hand, it grew together with *Salix caprea*, *Ulmus glabra* and with species of the genus *Sambucus* and genus *Rubus*.

C.5.2.1. *Rubetum idaei* Kaiser 1926, clearings dominated by *Rubus idaeus*

Raspberry was a relatively common species in the national park, especially above 800 m, but rarely dominated. Along with raspberry, a significant share of *Eupatorium cannabinum, Urtica dioica, Dactylis glomerata, Arctium lappa, Rubus hirtus* and *Chaerophyllum* sp. was identified (Figure 9).

C.5.2.2. Forest clearings, forest road edges (Aliance *Sambuco-Salicion* Tx. 1950, syn. *Astrantio-Corylion avellanae* Passarge 1978)

It is a habitat type that includes forest clearings and the edges of forest roads defined only at the forth level of the National Habitat Classification (NHC), where it mainly consists of a shrub layer of *Sambucus racemosa, Sambucus nigra* and *Salix caprea*. A total of 45 plots belonging to the willow community (*Salicetum capreae*) were identified. Since this community was not yet precisely classified, it was also synthesized at the fourth level, under the same C.5.2.2. code.

C.5.2.2. *Salicetum capreae* Schreier 1955, clearings dominated by *Salix caprea*

With a total of 45.9%, forest clearings dominated by *Salix caprea* were the most common forest clearing vegetation community type. *Salix caprea* was widely distributed in the national park area, although it rarely formed dominant stands larger than 1000 m². It rather grew in small groups or individually. Along with *S. caprea*, this community was also accompanied by other pioneer species, primarily *Acer pseudoplatanus*, *Populus tremula* and less often *Picea abies*. More than 60% of plots classified as type C.5.2.2. contained *Acer pseudoplatanus, Picea abies* and *Fagus sylvatica* in the tree layer, *Acer pseudoplatanus, Picea abies* and *Sambucus nigra* in the shrub layer and *Brachypodium sylvaticum, Eupatorium cannabinum, Rubus hirtus, Fragaria vesca, Salvia glutinosa, Carex sylvatica* and *Hypericum perforatum* in the herb layer. Also, a dominance of heliophilous species of early successional phases of devastated forests or deforested terrain was also present. Physically damaged or twisted willow trees were also quite often found on the plots, from whose shoots, fallen branches and roots juveniles often developed. Ruderal species were also common, while pasture and mowing species were less significant.

According to the research, three subtypes of willow stands occurring in different habitats were identified. In the first subtype, willow grew on the edges of former clearings and forests, where it built relatively narrow strips along the forest edges. The most beautiful examples of such stands were present in the Delićka meadow, with a little less than a quarter of a hectare (Figure 10). This subtype was dominated by *Pteridium aquilinum*, as well as *Eupatorium cannabinum, Urtica dioica, Brachypodium sylvaticum, Festuca sylvatica, Rubus hirtus, Cirsium arvense, Dryopteris filix-mas* and other species. The second most common subtype was occupied by former forest storage areas workers' dwellings. Today, these habitats represent extensions along forest roads under a similar progressive process. In addition to the willow, *Acer pseudoplatanus* was present in both tree and shrub layer, *Fagus sylvatica* was somewhat rarer, while among other species *Lonicera xylosteum, Eupatorium cannabinum, Brachypodium sylvaticum, Dryopteris filix-mas, Cirsium arvense, Hypericum perforatum, Salvia glutinosa, Senecio ovatus* and *Urtica dioica* stood out. The third subtype was found in the areas of former quarries, where steep and stony slopes were inhabited by *S. caprea*, next to, both in tree and shrub layer: *Pinus sylvestris, Picea abies, Acer pseudoplatanus* and *Fagus sylvatica*. Compared to the other two described subtypes, this one is characterized by a greater presence of the following species: *Buphthalmum salicifolium, Leontodon incanus, Artemisia vulgaris, Silene italica, Knautia drymeia, Juniperus communis* and *Populus tremula*.

Compared to potential habitat type communities studied in preparatory work, not a single area of *Senecioni fuchsii-Sambucetum racemosae* and *Senecioni-Epilobietum angustifolii* communities was recorded. *Epilobium angustifolium* was, on the other hand, individually recorded in microlocalities of bare and rocky surfaces of Magarčevac, Osinjak, Paljenik, Prosina, Razdolje and at the ridge of Veliki Javornik. Also, there were no plots where *Sambucus racemosa* dominated the area, but it was present on 6 plots in total; three in *Eupatorietum cannabini* and three C.5.2.2. Forest clearings, forest road edges communities.

Forest Clearing Structure

According to the results, the following structural characteristics of forest clearings were presented (Table 6).

The largest number of plots (94) of forest clearing habitats had an anthropogenic origin. Such habitats mostly included former warehouses along forest roads, workers' dwellings, the remains of former quarries created for excavation of materials for road construction, former agricultural areas, abandoned pastures, former mowing fields as well as wasteland created by the removal of sanitary trees. Only 4 forest clearings with natural origin were present as the result of the local canopy openings. All plots, except one, had an irregular type (shape). The regular one was the former circular-shaped meadow with an anthropogenic origin. Furthermore, the largest number (76) of forest clearings occupied a small area (less than 1000 m²), and only 22 belonged to the large category (greater than 1000 m²). Also, the largest number of forest clearings were located along the edge of the forest and along forest roads, while only 18 were located within the forest complex as a result of the local canopy openings.

Table 6. Forest clearing structure in Plitvice Lakes National Park.

Forest clearing structure		
Parameters		**Number of plots**
Origin	Natural	4
	Anthropogenic	94
Type (Shape)	Irregular	97
	Regular	1
Size	Small (<1000 m^2)	76
	Large (>1000 m^2)	22
Location	Forest Interior	18
	Forest Edge	80

Figure 8. *Eupatorietum cannabini* community along the forest road in Bračinovac.

Figure 9. *Rubetum idaei* community within the forest complex at Kriva locality.

Figure 10. Forest clearings, forest road edges species on the edge of Delićka meadow.

DISCUSSION

Based on the conducted research, the basic forms of habitat type C.5.2., forest clearings in Plitvice Lakes National Park, are relatively few. Apart from heterogeneous ecological factors and biogeographical position, the cessation of forest management (since 1949 and 1990) largely influenced the present state of forest structure as well as the development of other non-forested habitat types (Vukelić and Šapić 2013). The largest number of forest clearings in the area have not been used for more than forty years and are overgrown with a shrub layer of *Prunus spinosa, Crataegus monogyna, Juniperus communis, Ligustrum vulgare, Euonymus europaeus, Pteridium aquilinum* and other species of *Prunetalia spinosae* Tx. in 1952. order. The progressive dynamics are also emphasized by smaller groups of juvenile trees consisting of *Prunus avium, Acer campestre, Carpinus betulus, Pyrus pyraster* and *Malus sylvestris*. Such clearings occupy up to hundreds of hectares of area and are usually marked by toponyms according to the surname or nickname of the former user, e.g. Bobića krčevina, Sorića krčevina, Matića krčevina and Rodića krčevina. In addition, some forest clearings are overgrown with *Picea abies, Acer pseudoplatanus* and *Fraxinus excelsior* on the dolomite substrate with common pine, which is significant for Karleuša plase, Čujića krčevina, Šplejero lugovi, Delićka, Kolićka, Velika poljana and other localities. This modification of ecological conditions negatively affected and greatly hindered the development and maintenance of forest clearings (Vukelić et al. 2022).

The most fequent origin and the largest number of forest clearings in the national park area near forest edges, macadam forest roads and their extensions, especially in Kriva draga, Palež and Mileusnića draga, indicate the importance of anthropogenic activities in the development of these habitats. Due to the transport of forest products in the past, macadam forest roads were built relatively densely and their extensions were used for forest warehouses, dwellings and residence for workers. In addition, a dozen quarries were opened and used for construction and road maintenance. Almost none of them are in use today, but they are still maintained by annual mulching. Such forest clearings are predominantly overgrown with nitrophilous and herbaceous vegetation and both shrub and tree elements of overlapping communities of the surrounding forest ecosystem (Medak et al. 2023). This is also visible in an increased share of phanerophytes (P) life-form. Despite variability in their size, anthropogenic forest clearings are predominantly small, irregularly shaped and often under the influence of progressive dynamics.

Forest clearings with natural origin, on the other hand, are mostly associated with an individual or group tree removal caused by the canopy openings as a result of the influence of one or more environmental factors (Medak et al. 2023). This type of forest clearings in the national park is relatively small (< 1000 m^2), irregularly shaped, located within the stand complex and including a proportion of mostly mesophilic hemicryptophytes (*Aremonia agrimonoides, Fragaria vesca, Veronica urticifolia, Tanacetum macrophyllum, Cirsium vulgare, Sanicula europaea, Oxalis acetostella, Knautia drymeia, Galium lucidum, Brachypodium sylvaticum* and *Helleborus multifidus*). Although it is present in a much smaller proportion, numerous authors agree that this type of forest clearings plays a key role in maintaining both complex stand structure and heterogeneous vegetation units (Grubb 1977, Runkle 1989, Attiwil 1994, Clinton et al. 2000, Zeibig et al. 2005, Nagel and Diaci 2006, Bottero et al. 2011, Lanta et al. 2019, Lewandowski et al. 2021).

Furthermore, the research revealed a discrepancy between available information presented in the National Habitat Classification and the obtained data. Contrary to an increased share of generally stated Apiaceae, Asteraceae, Ranunculaceae and Liliaceae families, our data showed an increase only of Asteraceae (10.1%), Apiaceae (5.0%) and Ranunculaceae (3.9%) families. Liliaceae family, on the other hand, was very rare and included only 1 taxa (0.4%). This research also highlighted an increased share of Rosaceae (9.3%), Lamiaceae (7.8%), Poaceae (5.8%) as well as Brassicaceae family (3.9%).

The area also contains a large number of very different floral elements. Significant percentage of circumboreal floral elements (9.9%) shows specific microclimatic conditions of higher soil and air humidity throughout the year, with temperature inversion and smaller temperature variations. This is also confirmed by the dominance of hemicryptophytes (H), as well as a large proportion of geophytes (G). On the other hand, it is also important to mention somewhat smaller but significant proportion of Euro-Mediterranean species (3.6%), which confirms that the researched area is located on the border of different climatic influences and phytogeographic units.

In addition, a total of 11 strictly protected species (SZ), 6 nearly threatened (NT), 3 vulnerable (VU) species, 2 data-deficient (DD) and 4 endemic species indicate the importance of preserving this habitat type (Lanta et al. 2019). In order to preserve an optimal development of this habitat type, active measures may be needed. By removing species from the layer of trees and/or shrubs without diagnostic significance at the outermost edge of the forest clearing (e.g. *Fagus sylvatica*, *Abies alba*, *Picea abies*, *Acer pseudoplatanus*, *Corylus avellana*, *Prunus spinosa*, *Crataegus monogyna*, *Fraxinus excelsior* and *Juniperus communis*), an undisturbed development and expansion of the habitat would be created (Vukelić et al. 2022). Furthermore, potential measures for the preservation of forest clearings can include the removal of the existing lying trees and branches of older trees on edges, which may enhance light availability and at the same time prevent the spread of neighboring forest species. Also, the growth of diagnostic species located at the edge of the forest can be supported by mulching the roads as narrowly as possible (Vukelić et al. 2022). Although potential measures can contribute to biodiversity preservation and maintenance of the existing conditions, indiscriminate implementation can be counterproductive and unfavorable, leading to unwanted consequences in practice. It can also cause serious consequences to the ecosystem, including degradation and potential appearance of invasive species. Small forest clearings with natural origin located within forest ecosystems, as on plot 73, can very quickly become part of progressive syndynamics, thus reducing the benefits and effectiveness of implementation of such procedures. Also, the implementation of protection measures on steep and hard-to-access terrains can cause an undesirable erosion processes. For some forest clearings, on the other hand, e.g. on plot 84, which serves as a wild game (*Sus crofa*) habitat and is not threatened by transformation into another vegetation form, no conservation measures are needed. Adaptation of activity measures to specific ecological conditions of an individual area are necessary to preserve the uniqueness of their structural characteristics (Vukelić et al. 2022).

In addition to the plant communities of forest clearings classified within the National Habitat Classification (NN 27/2021, NN 101/2022); *Atropetum bella-donae* and *Telekium speciosae,* three new communities were identified. The area contains a certain number of localities with *Rubetum idaei* and *Eupatorietum cannabini* communities temporarily synthesized at the fourth level, under the C.5.2.1. code. Also, the largest part of the area belongs to *Salicetum capreae* community, temporarily classified at the fourth level, under the C.5.2.2. code. Such results significantly contribute to the expansion of the knowledge about this habitat type and supplement the currently valid National Habitat Classification (NHC).

By comparing the obtained vegetation data with available data of forest clearings in the surrounding countries, the following was presented. In this research, apart in the form of *Telekium speciosae* community, *Telekia speciosa* was found individually and in the composition of C.5.2.2. type within dominance of *Salix caprea*, as well as *Eupatorium cannabinum*. Optimal development of *Telekia speciosa* with species of similar sociological and ecological features can be present along *Petasites hybridus, Aruncus dioicus* and *Filipendula ulmaria* (Oroian et al. 2021). As confirmed by this research, *Atropa bella-donna* can also take part in forming forest clearing communities with many other species such as *Salix caprea, Sambucus racemosa, Verbascum thapsus, Fragaria vesca, Cirsium eriophorum, Epilobium angustifolium, Epilobium montanum, Lactuca virosa* and *Stachys alpina* (Matuszkiewicz 2001). Furthermore, the development of *Eupatorium cannabinum* in humid conditions of the national park area in composition of *Cirsium palustre, Urtica dioica, Angelica sylvestris, Deschampsia cespitosa, Succisa pratensis, Equisetum arvense* and *Lysimachia vulgaris* can also be found in black alder forests of juvenile development stages and on forest edges in Austria (Wallnöfer 1993). In less humid conditions, on the other hand, *Eupatorium cannabinum*, together with *Salix caprea* and *Ulmus glabra,* species of the genus *Sambucus* and *Rubus*, is also more common in mesophilic to neutrophilic varieties of beech and beech-fir stands. In the case of *Rubetum idaei* community, the dominance of other species over *Rubus idaeus* has also been suggested in other papers where mostly pioneer trees *(Betula pendula, Salix* sp., *Sambucus nigra, Sambucus racemosa)* and herbaceous species (*Calamagrostis epigejos, Epilobium angustifolium* and *Rubus fruticosus*) are developed on oligotrophic to eutrophic soils (Chytrý 2013). This community also represents the secondary vegetation type of clearings and meadows within the beech-fir stands and other communities in the montane zone.

The association with *Salix caprea* has been described by numerous European authors (Wallnöfer 1993, Matuszkiewicz 2001, Willner and Grabherr 2007, Chytrý et al. 2010, Chytrý 2013,). Compared to this short-lived community in the national park area that can be quickly replaced by other species, in the subalpine belt it can last for several decades. Such stands include *Larix decidua*, *Pinus sylvestris*, genus *Rubus*, *Sambucus nigra, Sambucus racemosa*, *Calamagrostis epigejos, Juncus effusus, Epilobium angustifolium, Fragaria vesca, Urtica dioica* and *Tussilago farfara*. Ruderal species such as *Artemisia vulgaris*, *Cirsium vulgare, Conyza canadensis* and *Lupinus polyphyllus* are also present.

As many authors already stated, forest clearings surely are characterized by structural uniqueness, specific flora composition and constant variability (White and Pickett 1985, Runkle 1989, Busing and White 1997, Fahey and Puettmann 2007, Schliemann and Bockheim 2011, Lanta et al. 2019). For greater knowledge and understanding of both vegetational and structural features of forest clearings as well as their differentiation in relation to other areas, additional research is needed.

CONCLUSIONS

The number of C.5.2. forest clearings habitat type within the forest stands in Plitvice Lakes National Park is relatively small. The reason for this is largely the cessation of most management activities in the area, which changed the forest structure by increasing the amount of both mature and closed stands. Based on the conducted research, a total of 98 plots of forest clearing habitats were established, mostly located on the Western and Northwestern part of Plitvice Lakes National Park. The largest number of forest clearings belong to the *Salicetum capreae*, followed by *Eupatorietum cannabini*, *Atropetum bella-donae*, *Telekia speciosa* and *Rubetum idaei* communities. A total of 257 species of vascular plants classified into 60 families were identified. The most represented family was Asteraceae, followed by Rosaceae, Lamiaceae, Poaceae, as well as Apiaceae. A relatively large share of species also belonged to Ranunculaceae and Brassicaceae. The highest relative representation of life-forms in the researched forest clearing habitat type were hemicryptophytes (H), followed by geophytes (G) and phanerophytes (P). Furthermore, the most represented chorologycal type in the area was Eurasian (20.6%). The habitat type also included several strictly protected (SZ), nearly threatened (NT), vulnerable (VU), data-deficient (DD) and endemic species, indicating the importance of preserving its optimal development.

The largest number of forest clearings located near forest edges and/or macadam forest roads and their extensions emphasizes anthropogenic activity impact in developing such habitats. Apart from the anthropogenic origin and marginal location, forest clearings in the area are mostly irregularly shaped, occupying a small area (less than 1000 m^2) and are often subjected to progressive succession. Adaptation of potential activity measures to specific ecological conditions of an individual area is therefore necessary to preserve the uniqueness of this habitat type.

The results of this work provide the first vegetational and structural data of forest clearings in the Plitvice Lakes National Park area, which can serve as a fundamental starting point for the necessary future research of this habitat type.

Author Contributions

JM, JV and NM conceived and designed the research, IS, JM and JV carried out the field data collection, IS processed the data and performed the statistical analysis, NM secured the research funding, JM and JV supervised the research, IS wrote the manuscript.

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Conflicts of Interest

The authors declare no conflict of interest.

Supplementary Materials

Supplementary File 1 - List of all plots included in C.5.2. Forest clearings habitat type, forest clearing communities and their structural features in Plitvice Lakes National Park

Supplementary File 2 - List of all plant species, families, life-forms and threat status in C.5.2. Forest clearings habitat type in Plitvice Lakes National Park

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