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Floristic composition as an indicator of destabilisation of lowland forest ecosystems in Posavina

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Abstract

Background and Purpose: *The succession of forests in the Posavina region follows a pattern from forests of black alder and ash through stands of pedunculate oak to pedunculate oak-hornbeam forests. In the past hundred years, this lowland area has been affected by a number of factors, among which anthropogenic influences hold a primary position. This has resulted in a considerable deviation from normal, natural succession. The purpose of this paper is to analyse the present condition, the degree of destabilisation and the future developmental trends of pedunculate oak stands by drawing on previous pedological, hydrological and vegetational research. One of the best indicators of the above is the ecoindicator values of the floristic composition.*

Materials and Methods: *Phytocoenological relevés were taken in 25 localities of both stable and destabilised forest ecosystems of pedunculate oak in Žutica Forest. The principles of the Zurich-Montpellier School were applied for this process. The numerical analysis was carried out by means of SYN-TAX 2000 software. JUICE 6.3 and CANOCO 4.5 were also used to process the relevés, construct the phytocoenological tables and correlate species compositions and vegetation types with ecological factors. The obtained results were compared with the results of earlier ecological research.*

Results: *Phytocoenological research revealed significant changes in the floristic composition. Ecoindicator values of plant species indicate a substantial change in ecological parameters and increased destabilisation, which leads to larger quantities of light, thermophilicity and humidity in sites. In addition, the sites are richer in nitrogen and the soil reaction becomes more basophilic, while central European species replace intermediary ones.*

Conclusions: *The investigated plots show a regression process contrary to the normal direction of vegetation development in lowland areas. A return has been observed from the final community to transitional communities, and in some localities even to initial and pioneer communities.*

INTRODUCTION

The succession of forests in the Posavina region follows a pattern from the forest of willow, poplar, black alder and ash, through stands of pedunculate oak to the forest of pedunculate oak and hornbeam. The succession and the ensuing changes are the result of both external ecological factors and the internal development of the community. In the past hundred years, the lowland region has been affected by a variety of factors, among which anthropogenic activities take precedence. This has resulted in a considerable deviation from the natural succession. Some of these activities follow natural processes and are not stressful. Consequently, the succession may be considered natural. This applies primarily to the lowland region of Croatia, where the areas covered with communities of dried sites have increased in comparison with more humid ones. However, different interventions in nature have brought about shocking changes to which the species and their ecological-biological traits have not managed to respond satisfactorily. The result is dieback of large forest complexes. Thus, plant communities have not changed progressively; instead, their entire development has been stopped and often taken back to the beginning. The best known such localities in the region of Croatian Posavina are the lowland forests of the Pokupsko Basin, the forests in the Turopolje-Lekenik area, Žutica near Ivanić-Grad and a large portion of the Spačva forests.

The most detailed research on destabilisation in forest ecosystems of pedunculate oak in Posavina was undertaken in the areas of Kalje and Posavske Nizinske Šume (Posavina lowland forests) near Sunja *(1–3)*, in Turopoljski Lug *(4)*, Pokuplje Basin *(5)*, Spačva *(6)*, Čazma Basin and Žutica Forest *(7–22)*.

In the meantime, new methods and techniques of phytocoenological relevé processing and analyses have been developed. These methods help to establish clear links between the floristic composition and the ecological factors decisive for the occurrence of plant species in a given site. They also monitor changes in ecological site conditions in both positive, and more importantly, negative (regressive) directions.

Since the most intensive vegetation-ecological research in the past ten years has been carried out in destabilised forest ecosystems in the Žutica management unit near Ivanić-Grad, this site was selected as the best place for the application of the new methods and techniques.

Forest ecosystems in the forest area of Žutica have been subjected to intensive ameliorative, technological and other anthropogenic impacts since very early times, but especially since the second half of the 20th century. The synergy of these impacts has led to sporadic changes and instabilities in forest ecosystems. This applies particularly to stands of pedunculate oak, where some parts have suffered extensive dieback and degradation of trees and stands. On the other hand, different syndynamic changes related to either the withdrawal or the expansion of certain plant species or forest communities have been observed in other parts. According to our research, about 700 ha (which is almost 20% of the total area under forest vegetation of pedunculate oak) of the most interesting and the most valuable forests of pedunculate oak have been exposed to highly intensive and abrupt external and internal impacts, as well as to extensive changes in the floral composition *(13, 14, 17)*.

A very similar or even worse situation can be noted in the majority of other European floodplain ecosystems in which the anthropogenic impact is exceptionally strong. This issue has been discussed by a number of authors, including Schlueter *(23)*, Klimo *(24)*, Štérba *et al. (25)*, Klimo & Hager *(26, 27)*, Čermak *et al. (28)*, Tockner & Stanford *(29)* and Prax *et al. (30)*.

The purpose of this paper is to analyse the present condition, degree of destabilisation and future developmental trends of pedunculate oak stands by drawing on previous pedological, hydrological and vegetational research. One of the best indicators of the above is the ecoindicator values of the floral composition. This research was undertaken in pedunculate oak stands growing in differently destabilised localities. It should be noted that the research is a sequel to previous research dealing with the same field and problem, and that it is intended to broaden our knowledge of this and similar lowland ecosystems.

MATERIAL AND METHODS

The collection of field data involved taking phytocoenological relevés from 25 localities in the central part of Žutica Forest. According to prior research and vegetation maps constructed by Rauš *(7, 8)*, Medvedović *(9)* and Baričević *(13, 14, 16)*, this area was once covered with pedunculate oak forests (predominantly forests of pedunculate oak and common hornbeam (*Carpino betuli-Quercetum roboris* /Anić 1959/ Rauš 1969) and to a lesser extent forests of pedunculate oak and *Genisto elata* (*Genisto elatae-Quercetum roboris* Horvat 1938). Today, however, it features different forms of forest vegetation as a consequence of weaker or more severe site destabilisation and the related dieback of pedunculate oak, e.g. forests of black alder with glossy buckthorn (*Frangulo-Alnetum glutinosae* Rauš 1968) and forests of narrow-leaved ash with summer snowflake (*Leucojo-Fraxinetum angustifoliae* Glavač 1959). Site selection was based on the principle of incorporating as wide a variety of situations as possible, ranging from the least destabilised to the most destabilised sites. Stands of pedunculate oak and common hornbeam in localities that represent a typical, undisturbed condition were taken as stable ones. It should be pointed out that our research is a direct continuation of previous research, especially that of Baričević from 2006. Forest vegetation was investigated using the principles of the Zurich-Montpellier School *(31)*.

All phytocoenological relevés were entered into a Turboveg database *(32)*. Numerical analyses were conducted with SYN-TAX 2000 software *(33)* using two methods of multivariate statistical analysis: Cluster Analysis and Multidimensional Scaling.

The relevés were processed and phytocoenological tables constructed by means of JUICE 6.3 software *(34)*. Diagnostic species obtained on the basis of the analysis of characteristic species (fidelity measure) were used for species classification in the phytocoenological tables.

The correlation of species composition and vegetation types with ecological factors (direct gradient analysis) was performed with CANOCO 4.5 software *(35)*. Ellenberg Indication values *(36)* were used to describe ecological conditions (light, humidity, soil reaction and soil nitrogen content). Average Ellenberg values were calculated for each relevé with JUICE 6.3 software.

The obtained results were compared with the results of earlier ecological research into soil properties (soil types, soil chemism, levels and chemism of ground and flood water), as well as climatic and hydro-ameliorative effects on the study area.

The Shannon-Wiener Index of Biodiversity was also calculated for each single relevé. Statistical processing was carried out with the Kruskal-Wallis non-parametric test, with Ellenberg ecoindicator values as dependent variables and predetermined groups as independent (grouping) variables.

RESULTS AND DISCUSSION

The results of the multivariate analysis of 25 phytocoenological relevés are shown in dendrograms (Figures 1 and 2).

The dendrograms show the grouping of phytocoenological relevés into four groups. According to the analysis of the floral composition, the first group consists of relevés 3, 7, 8, 9, and 10, which represent typical stands of pedunculate oak and common hornbeam (*Carpino betuli-Quercetum roboris*) of undisturbed character, and relevé 11, whose structure and floral composition are slightly disturbed. The second group is made up of relevés 1, 2, 12, 13, 14, 15, 16, 17 and 18, which currently represent stands of pedunculate oak and *Genista elata (Genisto elatae-Quercetum roboris*). The third group consists of relevés 4, 5, 19, 20, 21, 22 and 23, which represent stands of black alder and glossy buckthorn (*Frangulo-Alnetum glutinosae*), while the fourth group contains relevés 6, 24 and 25, representing stands of narrow-leaved ash with summer snowflake (*Leucojo-Fraxinetum antustifoliae*). A detailed floral composition is presented in the work of Baričević *(17)*, of which this research is a continuation.

To sum up: there are undisturbed conditions, slightly disturbed conditions, significantly disturbed conditions and exceptionally disturbed conditions, as well as extensive dieback of pedunculate oak in the range of natural occurrence of pedunculate oak communities. The newly formed stands of black alder and glossy buckthorn and of narrow-leaved ash with summer snowflake are of secondary origin. Their occurrence is due to the degradation of sites of pedunculate oak communities. In other large parts of Žutica, these communities grow in natural site conditions and therefore have a primary character. The causes of aberrations from normal forest associations of lowland regions, as well as the overall destabilisation of the Žutica forest ecosystem, have a synergistic nature. The principal causes include badly conducted regulation of waterways and melioration, and the related drop in groundwater levels and changes in the natural rhythm of floods, as well as the terrain being turned into waterlogged slots by a network of hard roads with inadequate draining systems *(13, 14)*.

The floral composition and ecoindicator values of plant species in phytocoenological relevés were further analysed according to the following a priori determined groups: *Leucojo-Fraxinetum* – LEUCOIO, *Frangulo-Alnetum* – FRANGULO, *Genisto elatae-Quercetum roboris* – GENIS, and *Carpino betuli-Quercetum roboris* – CARP and CARP1.

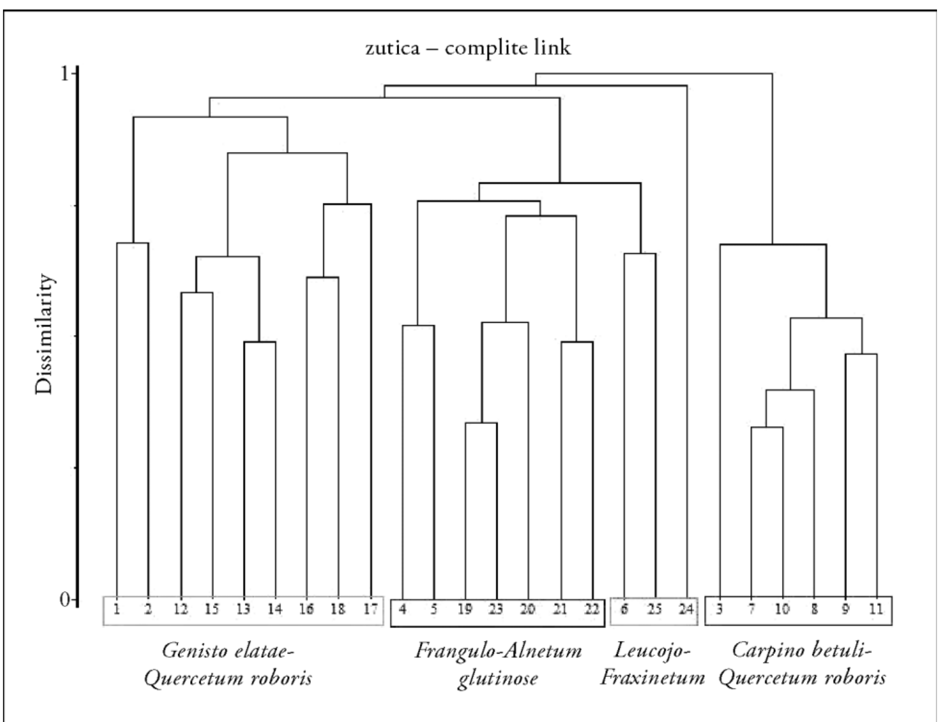

Figure 1. *Cluster Analysis – Complete Link Method.*

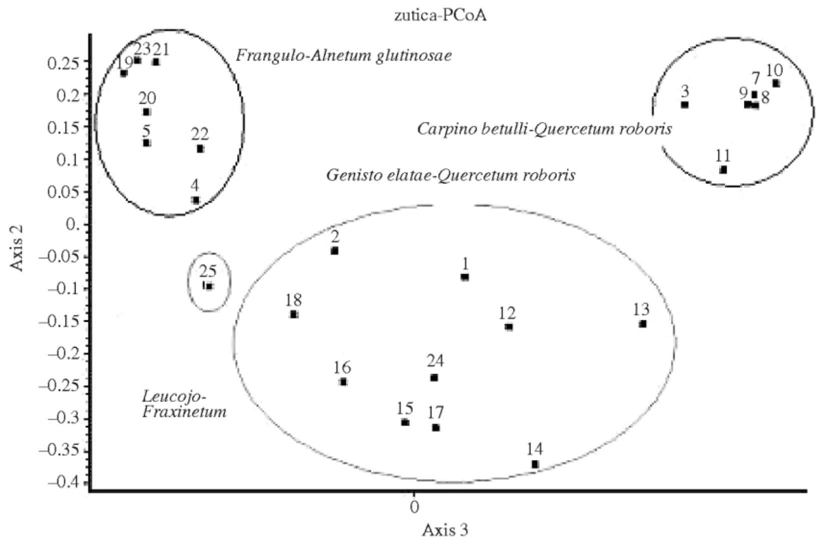

Figure 2. *Multidimensional Scaling – PCoA Method.*

TABLE 1

Shannon-Wiener Index and average values of Ellenberg ecoindicator values for every single phytocoenological relevé.

Group	Plot	Number of species	Shannon--Wiener Index	Light	Thermophilicity	Continentality	Moisture	Soil reaction	Nitrogen content
CARP	3	37	3.04	4.64	6.48	3.83	6.07	6.95	6.80
CARP	7	28	2.47	4.40	6.62	2.79	4.23	4.87	4.79
CARP	10	34	2.92	3.37	4.62	3.00	5.10	5.82	5.08
CARP	8	22	2.75	2.99	4.83	2.73	4.52	5.08	4.39
CARP	9	34	2.91	4.01	5.88	3.29	5.47	6.79	5.29
CARP1	11	36	3.08	3.63	4.97	2.46	4.84	5.84	5.12
GENIS	1	60	3.36	6.64	6.37	4.16	7.10	6.42	7.92
GENIS	2	55	3.2	7.89	6.44	3.48	8.92	5.18	7.38
GENIS	12	38	2.76	4.19	4.12	2.40	4.18	3.46	4.37
GENIS	15	27	2.61	7.45	6.51	4.24	8.99	4.74	5.99
GENIS	13	31	2.53	3.79	4.48	3.41	6.44	4.72	4.19
GENIS	14	42	3.08	2.98	3.42	1.51	4.33	1.85	2.54
GENIS	17	32	2.77	4.88	4.47	3.02	6.41	4.44	5.70
GENIS	18	26	2.54	5.41	6.01	3.54	8.29	7.82	7.67
GENIS	16	28	2.51	6.84	5.64	3.59	8.77	5.03	5.32
FRANGULO	4	39	2.97	8.60	7.51	4.66	9.74	9.59	8.62
FRANGULO	5	31	2.98	12.39	10.36	6.48	14.03	11.36	12.36
FRANGULO	20	26	2.6	8.22	7.81	5.26	8.93	7.41	8.16
FRANGULO	19	23	2.64	10.99	9.57	7.15	11.67	9.06	8.62
FRANGULO	23	21	2.36	8.49	6.77	3.89	9.59	7.59	6.08
FRANGULO	21	25	2.23	6.37	5.83	2.73	7.54	6.98	4.68
FRANGULO	22	35	2.82	7.11	5.88	3.60	8.23	7.52	6.76
LEUCOI	6	45	3.15	10.02	8.25	5.78	12.71	10.09	7.91
LEUCOI	25	32	2.56	5.27	5.07	3.24	6.56	3.30	4.00
LEUCOI	24	22	1.99	1.23	1.63	0.90	1.49	2.19	1.81

TABLE 2

Average Ellenberg index values for the selected ecological factors.

Group	Light	Termophilicity	Continentality	Moisture	Soil reaction	Nitrogen content
CARP	3.88	5.69	3.12	5.08	5.90	5.27
CARP1	3.63	4.97	2.46	4.84	5.84	5.12
GENIS	5.56	5.27	3.26	7.05	4.85	5.68
LEUCOI	7.65	6.66	4.51	9.64	6.70	5.96
FRANGULO	8.88	7.68	4.82	9.96	8.50	7.90

Thus, Ellenberg ecoindicator values (E_i) were calculated for every relevé (plot) on the basis of values for every single species and were augmented by a weight factor (W_i), which represents the weight value calculated as a specific weight of abundance and density. The Shannon-Wiener Index of Biodiversity was also calculated for every single relevé (Table 1).

Shannon-Wiener Index and average values of Ellenberg ecoindicator values for every single phytocoenological relevé.

Based on these analyses, average values were calculated for different relevé groups (Table 2, Figure 3). Relevé 24 in Table 2 was not taken into consideration due to an error in its selection or data processing (this will be established in new research).

Average Ellenberg index values for the selected ecological factors

If we analyse the results from Table 2, we can conclude that ecological parameters change drastically with a change in the degree of site destabilisation. This is best observed in basic ecological parameters (light, warmth, humidity), but also in other parameters.

The degree of site destabilisation increases with the succession direction of the communities *Carpino betuli-Quercetum roboris* → *Genisto elatae-Quercetum roboris* → *Leucojo-Fraxinetum angustifoliae* → *Frangulo-Alnetum glutinosae*, which is seen from the ecodiagram (Figure 4) and the following parameters:

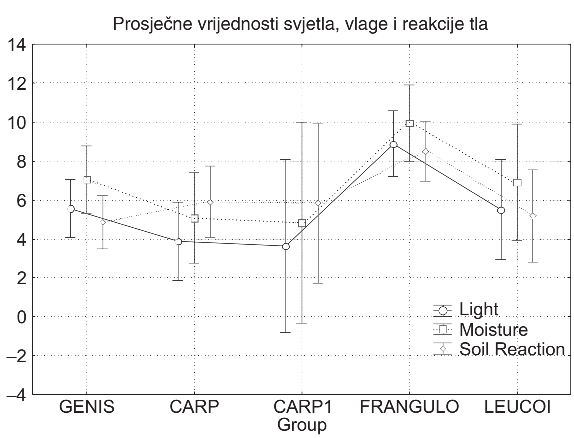

Figure 3. *Average values of the selected ecoindicator factors (soil reaction, moisture, light) according to group.*

1. starting from shaded and semi-shaded sites (E_i = 3.63), light increases to semi-illuminated sites up to the occurrence of predominantly and completely heliophitic species (E_i = 8.88);

2. site thermophilicity increases from moderately warm sites (E_i = 4.97) towards warmer and even near-Mediterranean sites (E_i = 7.68);

3. in terms of continentality, central European plant species (E_i = 2.46) replace sub-oceanic ones, ending in intermediary plant species (E_i = 4.82);

4. site humidity increases considerably from fresh sites (E_i = 4.84) through humid ones to wet and alternately flooded-wet ones (E_i = 9.96);

5. soil reaction also changes significantly, going from neutrophilic (E_i = 4.85) towards slightly to strongly basic (E_i = 8.50);

6. due to larger quantities of raw humus, the soil nitrogen content also increases from moderately rich (E_i = 5.12) to very rich and exceptionally nitrogen-rich sites (E_i = 7.90).

A regression process contrary to the normal direction of vegetation development in the Croatian lowland Posavina region was confirmed in the studied plots.

The goal of further analysis was to determine the existence of statistically significant differences in the values of Ellenberg indices for a priori defined groups, as well as to establish which changes in the index define a given group.

A non-parametric Kruskal-Wallis test was used for statistical processing. The results show significant differences in average *Ei* values relating to light, moisture and soil reaction (figure 5). In terms of groups, this is the difference between an undisturbed condition (*Carpino betuli-Quercetum roboris*) and a severely disturbed condition (*Frangulo-Alnetum glutinosae*). A more complete analysis of a larger number of relevés will probably confirm the same for *Leucojo-Fraxinetum angustifoliae*.

A very important parameter in the assessment of the condition and degree of destabilisation in certain sites and plant communities is biodiversity, or better said, a change in its value. Biodiversity was obtained with the Shannon-Wiener Diversity Index, a parameter commonly used in ecological research. Indices for single phytocoenological relevés are given in Table 1, and average values are presented in Figure 6.

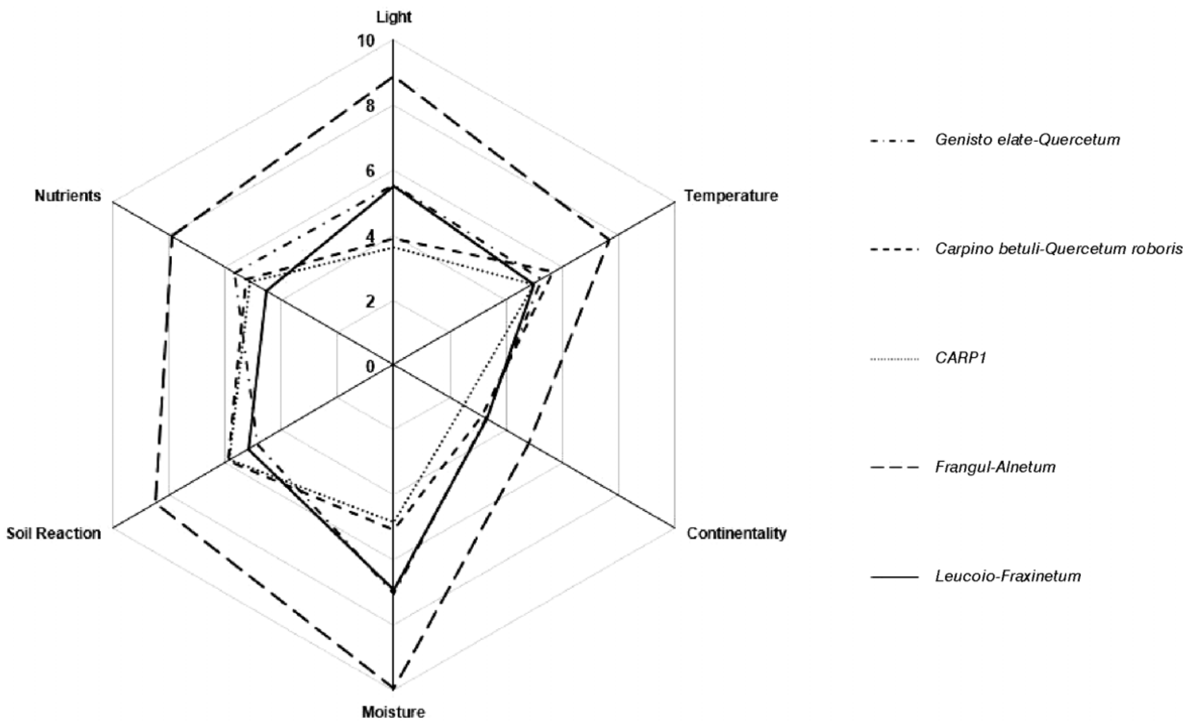

Figure 4. *Ecodiagram of average values of Ellenberg indices for different groups.*

Depend.: Light	Multiple Comparisons z' values; Light (New STATISTICA Spreadsheet (2)) Independent (grouping) variable: Group Kruskal-Wallis test: H (4, N= 25) =12.31543 p =.0152				
	GENIS R:12.000	CARP R:6.6000	CARP1 R:5.0000	FRANGULO R:20.429	LEUCOI R:12.000
GENIS		1.315437	0.902305	2.272470	0.000000
CARP	0,000,001		0.198456	3.208889	1.004681
CARP1	0,000,001	0.198456		1.960937	0.823688
FRANGULO	0,000,002	3.208889	1.960937		1.659578
LEUCOI	0,000,000	1.004681	0.823688	1.659578	

Depend.: Moisture	Multiple Comparisons z' values; Moisture (New STATISTICA Spreadsheet (2)) Independent (grouping) variable: Group Kruskal-Wallis test: H (4, N= 25) =11.10048 p =.0255				
	GENIS R:12.333	CARP R:6.4000	CARP1 R:6.0000	FRANGULO R:19.857	LEUCOI R:12.333
GENIS		1.445356	0.816371	2.028533	0.000000
CARP	1.445356		0.049614	3.122700	1.103909
CARP1	0.816371	0.049614		1.761212	0.745241
FRANGULO	2.028533	3.122700	1.761212		1.481431
LEUCOI	0.000000	1.103909	0.745241	1.481431	

Depend.: Soil Reaction	Multiple Comparisons z' values; Soil Reaction (New STATISTICA Spreadsheet (2)) Independent (grouping) variable: Group Kruskal-Wallis test: H (4, N= 25) =11.20281 p =.0244				
	GENIS R:8.6667	CARP R:12.200	CARP1 R:13.000	FRANGULO R:20.571	LEUCOI R:9.6667
GENIS		0.860718	0.558570	3.209704	0.203810
CARP	0.860718		0.099228	1.942571	0.471332
CARP1	0.558570	0.099228		0.962312	0.392232
FRANGULO	3.209704	1.942571	0.962312		2.147137
LEUCOI	0.203810	0.471332	0.392232	2.147137	

Figure 5. *Kruskal-Wallis test results.*

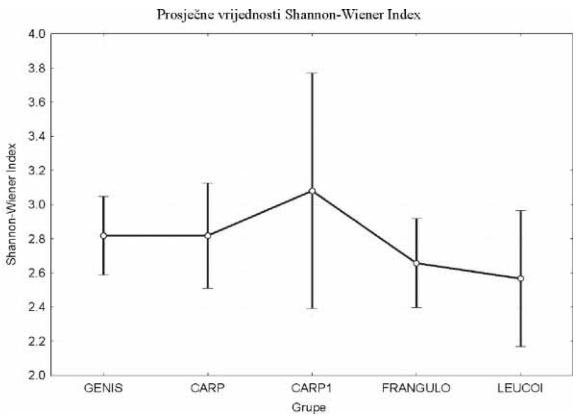

Figure 6. *Biodiversity indices for individual groups.*

As shown in Figure 6, the highest relative biodiversity was recorded in undisturbed conditions of the community *Carpino betuli-Quercetum roboris*. Biodiversity decreases with increased destabilisation in the order of vegetation succession *Genisto elatae-Quercetum roboris* → *Frangulo-Alnetum glutinosae* and *Leucojo-Fraxinetum angustifoliae*. However, the differences are too slight for the above to be considered a regular pattern.

In conclusion, the most valuable pedunculate oak stands in the Žutica area have experienced substantial changes which have severely degraded these stands. Syndynamically, in many of the localities the final community has reverted to transitional communities, and sporadically even to initial and pioneer communities.

Both the results of this and previous research confirm that sites in this area have experienced changes in their floral composition (*13, 14, 17, 21*). The same has been observed in other localities in Croatia with destabilised lowland ecosystems: the forest of Kalje *(1)*, the area of Sunja *(1)*, Turopoljski Lug *(4)*, the basin of the River Česma *(11)* and the Pokupsko Basin *(5)*.

The changes predominantly relate to increased humidity and light in the sites, as pointed out by Vukelić & Baričević *(37)*. Apart from vegetational research, the above trend has also been confirmed by the majority of other ecological investigations. Dekanić *(38)* uses the example of Žutica to explore the impact of the height of the groundwater table and its oscillations (waterlogging) on pedunculate oak dieback and the gradual invasion of black alder. Škorić & Vranković *(39)* conclude, on the basis of the results of soil hydrogenisation and the mass death of trees, that pedunculate oak dieback correlates with anaerobiosis. A particularly harmful impact is attributed to sluggish floodwater runoff caused by dense road networks *(40, 41)*. In addition, since the forest of Žutica is a retention area for high waters of the River Sava, the maximal flood height is much higher than normal. The forest area affected by floods has also increased, thus threatening the sites of pedunculate oak with common hornbeam with excessive humidity, which is particularly detrimental in the vegetation period *(42)*.

Research in the area of Kalje *(2)* shows that hydro-ameliorative operations in lowland ecosystems have brought about similar effects, leading to changed groundwater tables and a consequent change in overall water relations. The effects of uncontrolled and/or uncoordinated treatments in the environment of lowland forest ecosystems on changed groundwater levels and the frequency and duration of floods have been studied by a large number of authors *(43–48)*. The results of these changes in forests are reflected in the physiological weakening of the trees, decreased increment and eventual dieback and decline, which frequently leads to site weeding and waterlogging, as well as partial or complete degradation. According to these authors, particular importance is attributed to the duration of the presence of stagnant floodwater and the depth of groundwater. Forest dieback and decline evolve more slowly in the case of changed groundwater levels. The process is accelerated if surface water dynamics has been disturbed, while catastrophic dieback sets in when the water regime of a forest is generally disturbed and when decreased groundwater levels are combined with stagnant surface waters. Detailed research into water regimes has been undertaken by Mayer *(49–51)*, Mayer & Bušić *(52)*, Mayer *et al*. *(53)*, Medvedović *(9)*, and Škorić *et al. (54)*.

The analysis of the soil chemism of lowland ecosystems has also shown increased acidification of forest soils. The chemical soil structure has been disturbed by increased chloride content and increased sulphuric and nitrogen compounds *(55)*. Slightly higher than natural values of lead, copper and zinc concentration have been recorded in the Pokupsko Basin *(56)*. Research spanning a five-year period between 1995 and 2000 in north-western Croatia, in the area of Repaš, Česma and the Pokupsko Basin, also shows increased sediment quantities in forest ecosystems *(57)*.

It should also be pointed out that oil exploitation is partly responsible for changed site conditions in the area of Žutica, as discussed by Kovačević *(58)*, Prpić *et al. (59)*, Pernar & Bakšić *(18, 19)*, Pernar *et al. (20, 22)*, and Baričević *et al (21)*. This applies particularly to soil contamination in the localities of restored mud ditches and in depressions, as well as pedunculate oak dieback at points of oil pipe bursts and around oil wells.

Different forms of anthropogenic impact on the disturbance of floodplain forest functions are described in detail in the monograph *Floodplain Forests of the Temperate Zone of Europe (60)*. Tockner & Stanford *(29)* write that, based on a rough estimate in selected European countries, up to 95% of riverine floodplains have been lost and most of the remaining areas have been morphologically, hydrologically or ecologically modified by humans. This has been confirmed by numerous investigations, such as broader hydrological research into the soil of floodplain forests *(30)*. Research from particular areas such as that of the River Morava *(25)*, and research from the same or slightly broader area *(24, 28)* has shown decreased humidity in floodplain systems caused by the absence of floods and a drop in the groundwater table. This in turn causes changes in the floral composition, soil chemism and transpiration quantity. As a result, the species adapted to the new conditions survive, while others disappear. In some areas, increased groundwater levels have been recorded above dams and decreased ones below *(23)*. Therefore, management in such areas requires a detailed and individual approach.

It is therefore very important to recognise changes in the site (floral composition) on time and to react adequately in order to stop regression and initiate progression processes. It is important to emphasise that species of ground layer before reacting then species from the layer of trees.

The results of this research confirm and additionally define earlier investigations in this and other localities with destabilised forest ecosystems of pedunculate oak in Posavina, and can be applied to the entire area.

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