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LOW UNDERSTORY CONDITION IN AN OAK FOREST IN HUNGARY, 1972 AND 2022 – SÍKFŐKÚT PROJECT IS 50 YEARS OLD

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Abstract: Serious oak decline was first detected in 1979-80 in a mixed sessile oak–Turkey oak forest (*Quercetum petraeae-cerridis* Soó 1963). This decline resulted important structural changes in the understory shrub layer. Despite of this, relatively few studies deal with shrub communities and shrub layer dynamics after oak death. The goals of this research were to determine the conditions of low shrubs and analyse the possible changes in this layer after 5 decades from the beginning of Síkfőkút research. Specimens which were lower than 1.0 m in height were categorized as low shrubs in the shrub community. In 1972 and in 2022, 16-17 native low shrub species were observed in the understory; 15 species were present continuously in the forest. The density of low shrubs was 87401 and 17317 specimen ha^{-1}. The most common low shrub species was *Ligustrum vulgare* and 5 decades later *Quercus petraea* with 24.1% and 37.8% ratio. The mean height and mean diameter of low shrub species changed among 10.3-67.0 cm and 1.5-7.5 mm. The mean cover of these shrubs fluctuated between 35 cm^2 and 2026 cm^2 based on the two measured year. Our results suggest that the low shrub layer responded negatively to the biotic and abiotic factors under 5 decades; this is especially true to the density, cover and diversity indices of species.

Keywords: low shrub layer, oak decline, density, mean size, foliage cover

INTRODUCTION

Oak decline has been described as a widespread and complex phenomenon in many countries (Tomiczek 1993, Sonesson and Drobyshev 2010). An increase in the death of oak species has been observed in many regions of Hungary since 1978 (Igmándy 1987). In the Síkfőkút research stand (*Quercetum petraeae-cerridis* Soó 1963) species composition of the canopy was stable until 1979 and the healthy *Quercus petraea* Matt. L. (sessile oak) and *Quercus cerris*

L. (Turkey oak) also remained constant. Serious oak decline was first reported in 1979–80 (Kotroczó *et al.* 2005) and by 2017, 62.9% of the oaks had died (Misik and Kárász 2020). This decline resulted many significant changes in the condition of shrub layer on Síkfőkút (Misik *et al.* 2013, 2014).

Understory and overstory relationships are complex and mutual but are dominated by the canopy structure and condition (Burrascano *et al*. 2011, Burton *et al*. 2011, Cutini *et al*. 2015). Shrub layers of forest ecosystems change dynamically and respond sensitively to the environmental changes (Chipman and Johnson 2002, Rees and Juday 2002). They are strongly related to the composition and structure of the overstory (Palik and Engstrom 1999, Chianucci *et al.* 2016). Shrub species play a major role in the cycles of some essential nutrients, including the dynamics of nitrogen, potassium and carbon (Gilliam 2007, Juhos *et al.* 2021). The shrub layers are directly contributes to forest biodiversity (Kerns and Ohmann 2004, Aubin *et al.* 2009), including compositional and structural diversity, enhancing the aesthetics of forest ecosystems and helping to protect watersheds from erosion (Alaback and Herman 1988, Halpern and Spies 1995, Muir *et al.* 2002). Shrubs provide food and habitat, among others, for song-birds, forest ungulates and arthropoda (González-Hernández *et al.* 1998, Yanai *et al.* 1998), can mitigate forest decline and influence forest regeneration through affecting light availability (Kunstler *et al.* 2006). Relatively few studies deal with shrub communities and shrub layer dynamics after oak death and the relationship between the trees and shrubs (Légaré *et al.* 2002).

In Hungary, the interdisciplinary, long-term biosphere research program "Síkfőkút Project" was established within the framework of the IBP (International Biological Program) organized by the ICSU (International Council of Scientific Unions) and the MAB (Man and Biosphere Program) launched by UNESCO. In our country, the LTER projects carrying out long-term ecological research were partly created from these. The Síkfőkút Project is also such a scientific research program, 50 years ago this year. The entire research concept was presented in detail by Pál Jakucs in his paper (Jakucs 1973). In the predecessor institution of Eszterházy Károly Catholic University, Imre Kárász former department head and institute director directed the extensive investigation of production and structural condition in the shrub layer from the beginning. These

studies included research on the species richness and number of individuals (density), biomass and root structure studies, and measurements of the size and foliage cover of the shrub's species (Kárász 1991).

Misik *et al*. (2013) described the possible responses of parameters of understory shrub layer to the remarkable changes in stand density on the study site. Misik *et al*. (2014) reported the dynamics behind the increase in the sizes of woody species and the structure of the new subcanopy layer below the canopy. The aim of the study was to investigate the composition, size condition, foliage cover and diversity of low understory in the mixed oak forest and analysed how low shrub layer changed after five decades of the structural measurements in the monitoring plot.

MATERIAL AND METHODS

Study site

The research site (Síkfőkút Project) was established in 1972 by Jakucs (1985) and is located in the Bükk Mountains (47°552 N, 20°462 E) in the north-eastern part of Hungary at an altitude of 320-340 m a.s.l. and 6 km from the city of Eger (*Figure 1A*). The continuity of long-term research the forest section in order to ensure it, in 1976 the forest stand was declared a nature reserve with a nationally important (Jakucs 1985). Management and maintenance of the 27 hectares protected area is the responsibility of the Bükki National Park Directorate. The study area belong to the ILTER (International Long-Term Ecological Research) sites and has been used for the long-term study of forest ecosystems. Mean annual temperature is 9.9 °C and mean annual precipitation ranges typically from 500 to 600 mm. Descriptions of the geographic, climatic, soil conditions, and herbaceous layer were reported in detail by research papers (Kiss and Berki 1996, Koncz *et al.* 2010, Switoniak *et al.* 2014). The mixed oak fores*t* community with a dominant canopy of *Q. petraea* and *Q. cerris* deciduous tree species structure is presented in the works of Mázsa *et al*. (2005), Kotroczó *et al*. (2007) and Fekete *et al*. (2017). Both oak species are important dominant native species of the Hungarian natural woodlands. The long-term dynamics of understory shrub layer are described among others in works of Misik *et al*. (2013, 2017) and Misik and Kárász (2022). The plots under study were made up of

evenly aged temperate, deciduous forest that was at least 110 years old and had not been harvested for more than 55 years.

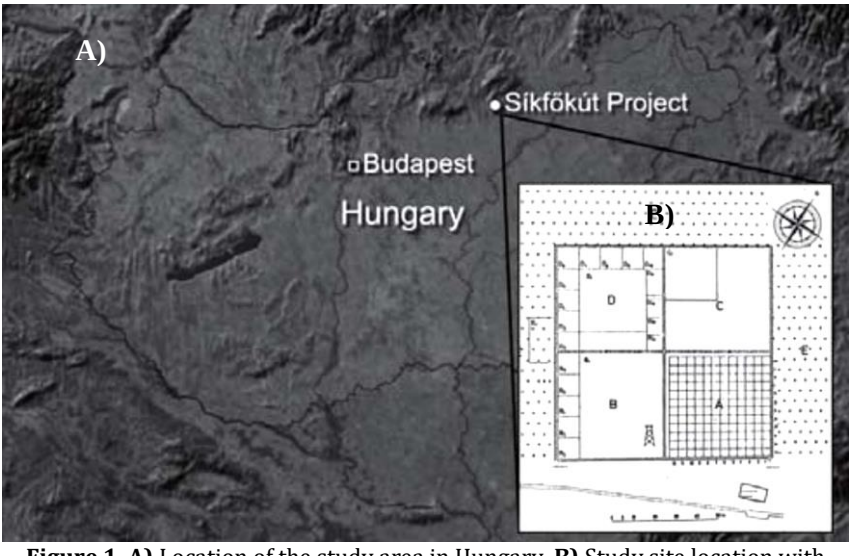

Figure 1. A) Location of the study area in Hungary. **B)** Study site location with plots (Misik and Kárász 2022)

Sampling and data analysis

The structural condition of the low shrubs was monitored on "A" plot at the research site, 48 m × 48 m in size; the plot was subdivided into 144 pieces 4 m × 4 m permanent subplots (*Figure 1B*). The subplots were established in 1972; the understory data collected at subplots measured during the 1972 and 2022 vegetation periods (in June or in July) on site. The dominant and co-dominant shrub specimens of the vegetation were lower than 1.0 m of height were categorized as low understory. Oak stems < 50.0 cm and between 50.0 and 100.0 cm of height were inventoried and categorized as oak seedlings and oak saplings.

The following measurements were carried out for low shrub species in each subplot: species composition, species density, height and diameter, mean foliage cover of species and finally diversity indices. The shrub specimen's density was extrapolated for one hectare. It was recorded the specimen height with a tape measure with an accuracy of 1.0 cm and the diameter at a height of 5.0 cm above the soil surface with a digital calliper. In the low

shrub layer, a number of specimens were randomly selected in proportion to the species density to determine the size parameters. The foliage cover of specimens was determined with the tape measure, with two perpendicular measurements laid on the foliage. The mean foliage area was given in square cm. Following diversity indices were used: Shannon-index (H) (*Eq. 1*) and Evenness (E) (*Eq. 2*).

$$H' = -\Sigma (p_i \times \ln p_i) \qquad (1)$$

$$E = H'/H_{max} = H'/\ln S \qquad (2)$$

Where: p_i – proportion of specimens found in the i^{th} species, S – total number of species in the shrub layer. Evenness was calculated as the ratio of observed diversity (*H*) to maximum diversity (H_{max}) (Magurran 1988).

RESULTS

Composition and density

Sixteen and seventeen native low shrub species were identified across the entire study area in 1972 and five decades later; fifteen species were present continuously in the monitoring plot. Species composition of low understorey was essentially constant. In 2022 two new species were identified in the plot compared to 1972: *Tilia cordata* Mill. (small-leaved linden) and *Quercus pubescens* Willd. (downy oak) occurred with a few specimens; *Sorbus torminalis* L. (checker tree) disappeared from the site after 50 years (*Table 1*).

The density of shrub layer per hectare was 87.401 specimens at the first survey. The most common low shrub species was *Ligustrum vulgare* L. (wild privet) with a 24.1% ratio of all low specimens; *Euonymus verrucosus* Scop. (spindle tree) and *Cornus sanguinea* L. (common dogwood) followed them in 1972. 50 years later the most common low shrubs were *Q. petraea* with 37.8% and *E. verrucosus*. The total density decreased remarkably to 2022, from 87401 to 17317 individuals' ha^{-1} below 1.0 meter in height. In the low shrub community, *Q. petraea* was the most common oak species with a 25.2% average ratio of all low shrubs based on data from the 1972 and 2022 surveys. In the last 50 years, we observed

the largest decrease in the number of individuals, two orders of magnitude, in the species *L. vulgare* and *C. sanguinea* (*Table 1*).

Table 1. Species composition and density condition of the low shrub layer on the Síkfőkút mixed oak forest in 1972 and in 2022.

species	1972			2022		
	density ind.	density ind. ha^{-1}	rate %	density ind.	density ind. ha^{-1}	rate %
A. campestre	1313	5699	6.52	355	1541	8.90
A. tataricum	1690	7335	8.39	69	299	1.73
C. mas	221	959	1.10	8	35	0.20
C. sanguinea	3150	13673	15.64	67	291	1.68
Cr. monogyna	381	1654	1.89	49	213	1.23
E. europaeus	1793	7782	8.90	69	299	1.73
E. verrucosus	3387	14700	16.82	1429	6202	35.81
J. regia	11	48	0.55^{-3}	6	26	0.15
L. vulgare	4852	21059	24.09	211	916	5.29
Lo. xylosteum	179	777	0.89	16	70	0.40
P. avium	1	4	0.50^{-4}	12	52	0.30
Q. cerris	334	1450	1.66	88	382	2.21
Q. petraea	2526	10963	12.54	1510	6553	37.84
Q. pubescens	0	0	0	91	395	2.28
Rh. cathartica	181	786	0.90	3	13	0.75^{-3}
R. canina	117	508	0.58	4	17	0.98^{-3}
S. domestica	1	4	0.50^{-4}	0	0	0
T. cordata	0	0	0	3	13	0.75^{-3}
total	20137	87401	100	3990	17317	100

Size condition

The mean shoot height of the detected shrub species changed between 10.31 cm and 66.96 cm in the low shrub layer based on the two survey years. It was measured the lowest mean height by *Rosa canina* L. (dog rose) and the biggest mean height by *Lonicera xylosteum* L. (European fly honeysuckle) individuals in the low shrub community. 5 decades later, we recorded the minimum mean height by *Q. petraea* seedlings and the maximum value by *Cornus mas* L. (European cornel). It was recorded between 1.46 mm and 7.51 mm mean diameter values of the low shrubs in 1972 and in 2022. *E. europaeus* had got the thinnest shoot diameter from 1972; in this year *Cr. monogyna* had got the thickest shoot. 5 decades later, we recorded the minimum diameter value by *Q. petraea* and the maximum value by *C. mas.* Based on the above data in 2022 the

largest low species was identified as *C. mas* with 56.30 cm mean height and 6.90 mm mean diameter (*Table 2*).

Table 2. Height and diameter condition (means ± standard deviation) of the low shrub layer on the Síkfőkút mixed oak forest in 1972 (N = 423) and in 2022 (N = 549).

species	1972		2022	
	mean height (cm±S.D.)	mean diameter (mm±S.D.)	mean height (cm±S.D.)	mean diameter (mm±S.D.)
A. campestre	32.93±7.12	4.42±1.03	17.51±5.67	3.37±1.04
A. tataricum	29.13±14.26	3.54±1.46	13.64±9.31	2.04±1.12
C. mas	42.24±23.55	5.12±2.64	56.30±28.55	6.90±4.09
C. sanguinea	43.41±28.48	3.19±1.75	29.65±19.35	2.93±1.15
Cr. monogyna	43.70±19.89	7.51±3.48	36.56±23.90	6.27±2.98
E. europaeus	17.55±6.71	2.01±0.89	11.13±4.54	2.37±1.51
E. verrucosus	29.12±16.67	3.53±2.08	20.49±14.27	3.29±1.37
*J. regia**	23.22±12.04	3.20±2.96	47.90±21.64	4.50±2.33
L. vulgare	40.90±24.46	3.14±1.61	31.44±19.19	3.55±1.44
*Lo. xylosteum**	23.22±12.04	3.20±2.96	42.10±24.18	4.46±2.46
*Q. cerris**	23.22±12.04	3.20±2.96	11.74±4.72	1.86±1.04
Q. petraea	22.69±7.36	3.83±2.34	10.31±6.20	1.46±0.99
Q. pubescens	-	-	12.54±3.74	1.61±0.32
*P. avium**	23.22±12.04	3.20±2.96	11.88±5.36	2.70±1.90
*Rh. cathartica**	23.22±12.04	3.20±2.96	12.63±1.89	1.67±0.50
R. canina	66.96±33.91	3.88±0.93	14.40±6.37	2.00±0.31
*S. domestica**	23.22±12.04	3.20±2.96	-	-
T. cordata	-	-	16.73±7.77	5.83±2.13
mean	**35.60**	**3.87**	**21.72**	**3.34**

*The mean size values of these species were measured in total in 1972.

The highest species based on the data of the two surveys is *C. mas* with 49.27 cm; the thickest diameter measured by *Cr. monogyna* with 6.89 mm. The mean height and diameter of low shrub species decreased from 35.60 cm to 21.72 cm and from 3.87 mm to 3.34 mm (*Table 2*).

Foliage cover

The mean cover of the shrub species changed between 68 cm^2 and 432 cm^2 in the low shrub layer in1972. It was measured 35-2026 cm^2 mean foliage cover by the low species of the shrub community five decades later. The maximum cover values were detected for *C. sanguine* and *A. tataricum* species with 432 cm^2 and 403 cm^2 under the first investigation. By far the biggest mean foliage cover was detected for *L. xylosteum* with 2026 cm^2. It was recorded the lowest cover by *E. europaeus* and *P. avium* with 68 and 35 cm^2 in the years under review. The mean cover of all low shrubs decreased considerably, from 455 to 280 cm^2 for this year (*Table 3*).

Table 3. Foliage cover condition (means ± standard deviation) of the low shrub layer on the Síkfőkút mixed oak forest in 1972 (N = 858) and in 2022 (N = 674).

species	1972		2022	
	mean cover (cm^2±S.D.)	measured shoots number	mean cover (cm^2±S.D.)	measured shoots number
A. campestre	341±382	43	217±281	113
A. tataricum	403±130	73	94±104	30
C. mas	189±246	15	571±661	4
C. sanguinea	432±205	62	66±181	52
Cr. monogyna	354±243	87	331±295	16
E. europaeus	68±39	47	39±35	41
E. verrucosus	359±317	148	78±75	153
*J. regia**	339±278	88	534±339	4
L. vulgare	308±296	106	434±453	65
*Lo. xylosteum**	339±278	88	2026±1268	10
*Q. cerris**	339±278	88	43±20	20
Q. petraea	334±175	124	57±131	125
Q. pubescens	-	-	60±44	25
*P. avium**	339±278	1	35±25	7
*Rh. cathartica**	339±278	88	50±4	3
R. canina	113±64	63	64±50	3
*S. domestica**	339±278	1	-	-
T. cordata	-	-	66±46	3
mean	**455**	**-**	**280**	**-**

*The mean cover values of these species were measured in total in 1972.

Diversity indices

Diversity indices varied between 0.41 and 2.16 in the understory shrub layer under 50 years. Shannon-Wiener index was between 1.08 and 2.16 in two years. The highest index was recorded in 1972 the total low shrub layer; by 2022, we measured a significant decrease in the diversity index values. In the low shrub layer was measured only 1.08 Shannon index value without oak seedlings and saplings in 2022. Evenness index varied between 0.41 and 0.75 in the low understory. It was detected a low difference between the low shrub layer with or without oak seedlings in 1972. 5 decades later, it was measured only 0.57 and 0.41 Evenness value with and without low oak specimens (*Table 4*).

Table 4. Shannon and Evenness indices of the understory shrub layer on the Síkfőkút mixed oak forest in 1972 and in 2022.

year	1972		2022	
index	low shrub layer	low shrubs without oaks	low shrub layer	low shrubs without oaks
Shannon	2.1571	1.9892	1.6191	1.0810
Evenness	0.7463	0.6922	0.5715	0.4096

DISCUSSION

The consequences of tree decline cause notable changes in the light and stand thermal conditions which led to structural changes of the understory (Chapman *et al.* 2006). Our results suggest and confirm that the decreasing canopy oak density led to the significantly structural changes of the shrub community. Fifteen native woody species as constant low shrubs were identified across the long-term study area since the first survey. In the past 5 decades despite the important oak decline; there is only two new low shrub species established in the study site. *T. cordata* and *Q. pubescens* was established in the forest as new woody species (*Table 1*). Similarly to our site, in the Vár-hegy forest reserve of Hungary the species composition of understorey (herb and shrub layer) did not change after oak decay in the 1970s and 1980s (Horváth 2012). The total shoot density of low understory decreased considerably, essentially reduced by a fifth from 1972 to 2022 on Síkfőkút site (*Table 1*).

Results of Grime (1966) suggested that shade tolerance rate depends largely on the capacity for germination and seedling establishment in the understory environment. The shade-intolerant species can survive and grow in the understory, among others in the low shrub layer, producing multi-layered and multi-aged forest stands (e.g. Muir 1993, Paré and Bergeron 1995, Volney 1998). The mean height of the low shrub species changed between 10.3 cm and 67.0 cm in the shrub community for two years. It was recorded between 1.5 mm and 7.5 mm mean diameter values of these shrubs. Based on size condition in the study site tolerant and dominant low shrub species with higher individuals density are *L. vulgare* and *Cr. monogyna* (*Table 2*).

Results from Kerns and Ohmann (2004) suggest that in the Oregon forest structure, stand development, site disturbance

history and other environment conditions all interact to influence the understory foliage cover. Total foliage cover of the understory shrub layer increased slightly, but non-significantly in a mature oak forest stand of the USA, from 45.0% in 1950 to 51.0% in 1969 and 1979. Contrary, the Shannon diversity index increased considerably, from 0.06 to 0.71 in 1979 (Davison and Forman 1982). On Síkfőkút site the mean cover of shrub species decreased notably. The mean cover values changed between 35 cm^2 and 2026 cm^2 in the low shrub layer (*Table 3*).

Shannon index and Evenness of the low understory varied among 1.08–2.16 and 0.41–0.75 in 1972 and in 2022. Shannon-Wiener and Evenness diversity indices of the low shrub layer decreased considerably from 1972 to 2022 parallel to the decreased in the individual density of low shrubs. The highest negative difference was detected for Evenness index without oaks in the low shrub layer (*Table 4*). De Grandpré *et al*. (2011) results suggested that the Shannon index increased significantly ($P < 0.001$) with time since treatment application in Canada; along a foliage gap of canopy severity gradient in old-growth and mature forest stands. According the paper of Onaindia *et al*. (2004) to use Shannon diversity and Evenness indices to evaluate the effects of disturbances in temperate forest stands.

CONCLUSIONS

Our most important results from 1972 and 2022 suggest that the low shrub layer responded negatively to the biotic and abiotic factors under 5 decades; this is especially true to the density, cover and diversity indices of species. Important decreasing also observed in the density, mean height, foliage cover and diversity indices by 2022. Forest compensated for the dead oak trees by forming a subcanopy layer between 8.0-13.0 m in height with *Acer campestre* L. (field maple), *Acer tataricum* L. (Tatar maple) and *C. mas* from the starting of oak decline. Especially field maples can influence on the density and mean size condition of low understory species by through it controlling ecosystem processes such as light transmittance and nutrient cycling. All information of our study will allow us to better understand the long-term shrub community development and to develop use and management after the serious oak decline. More research is needed to gain a better

understanding of the relationship between oak canopy density and low shrub layer development, especially the long-term tendencies in density, size, cover and diversity condition.

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