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# LONG-TERM RELATIONSHIP BETWEEN OAK DECLINE AND SHRUB GROWTH DYNAMICS IN AN HUNGARIAN OAK FOREST, 1972-2017

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## ABSTRACT

Long-term structural dynamics of shrub layer of temperate oak forest communities were not extensively reported in published studies. The serious oak decline was first reported in 1979-80 and nowadays 63.0% of canopy oak trees died in a forest stand. The data were used to obtain (1) quantitative information on shrub layer growth, including height (H) and shoot diameter (DSH) condition and basal area (BA) values; (2) structural information on foliage cover rate of the shrub layer, mean cover of some shrub species; (3) comprehensive description from the ecological processes in the shrub layer in the last 45 years and our objective was (4) to analyze the possible effects of oak decline on the shrub growth dynamics. The following measurements were carried out in the 48 × 48 m plot: shoot height, shoot diameter, basal area and foliage cover of each individuals in the high shrub layer. Correlation analysis confirmed that significant positive relations were between mean H, mean DSH of the dominant woody species (*Acer campestre*, *Acer tataricum* and *Cornus mas*) and oak tree density between 1972 and 2017. The decreasing oak tree density did not show detectable impact to the co-dominant shrubs growth. There was a low significant association between number of oak trees and basal area of high shrub layer. Finally, there was a statistically significant interaction between mean cover of *A. campestre* and *C. mas* and oak trees. The findings of the study indicate that forest responded to oak decline with significant structural rearrangement in the shrub layer.

**Keywords**: *Acer campestre*, *understory, height, diameter, mean foliage cover.*

## INTRODUCTION

Shrub layers of forests change dynamically and respond sensitively to the environmental changes (Chipman and Johnson, 2002; Rees and Juday, 2002). They are strongly related to the structure and composition of the tree layer (De Grandpré *et al*., 1993; Klinka *et al*., 1996). Understory plants are important components of forests because shrubs play a crucial role in the cycles of some essential nutrients, including the dynamics of N, K and carbon (Gilliam, 2007). The shrub layers of forests are directly contributes to the forest biodiversity (Kerns and Ohmann, 2004; Aubin *et al*., 2009), enhancing the aesthetics of forest ecosystems and helping to protect watersheds from erosion (Alaback and Herman, 1988; Muir *et al*., 2002). Shrubs can mitigate forest decline and influence forest regeneration through affecting light availability (Kunstler *et al*., 2006). On the other hand, tree and shrub individuals may compete for resources such as light, nutrients, or water during later stages of development (Wang et al., 2016). The shrub's cover may also vary along with the changes in tree density (Hallinger *et al*., 2010).

Serious oak decline was first reported in 1979–80 from our study site, heavily affecting *Quercus petraea* Matt. L. (sessile oak) individuals, and by 2017, 62.9% of canopy oak trees had died (from 816 living trees to 303 trees $ha^{-1}$). An increase in the decline of living oak trees was reported in many regions of Hungary since 1978 (Kotroczó *et al*., 2007). Many biotic and abiotic factors have been identified as important in oak decline events, such as extreme weather conditions (Drobyshev *et al*., 2008; Bolte *et al*., 2010), insect fluctuations (Moraal and Hilszczanski, 2000), disease outbreaks (Mistretta, 2002) or climate change, air pollution and fires (Signell *et al*., 2005; Kabrick *et al*., 2008). The resulting changes in the forest stand were described in many papers (Jakucs, 1988; Kotroczó *et al*., 2005; Mészáros *et al*., 2011; Misik *et al*., 2014, 2017).

Few published papers have investigated the long-term dynamics and structural changes in the understory shrub layer of deciduous oak forests (Alaback and Herman, 1988; Chapman *et al*., 2006; Gracia *et al*., 2007; Gazol and Ibáñez, 2009; Chapman and McEwan, 2016). Our comprehensive investigations play a gap-filling role.

The research data were used to obtain (1) quantitative information on shrub layer growth, including height (H) and shoot diameter (DSH) condition and basal area (BA) values relation with oak tree density; (2) structural information on foliage cover rate of the shrub layer, mean cover of some shrub species relation with oak tree density; (3) comprehensive description from the ecological processes in the shrub layer in the last 45 years and our objective was (4) to analyse the possible effects of oak decline on the shrub growth dynamics.

## MATERIAL AND METHODS

The 24ha reserve study area is located in the Bükk Mountains of northeast Hungary (47°55′ N, 20°46′ E) and at an altitude of 320–340 m above sea level. Descriptions of the geographic, climatic parameters, soil conditions, and vegetation of the forest were reported in detail by Jakucs (1985, 1988). The most common deciduous forest association in this region is *Quercetum petraeae-cerridis* Soó 1963 (sessile oak−Turkey oak) forest with a dominant canopy of *Q. petraea* and *Quercus cerris* L. (Turkey oak). Both oak species are important dominant, native tree in Hungarian natural woodlands.

Monitoring activities started in 1972 and it was repeated in 1982, 1988, 1993, 1997, 2002, 2007, 2012 and finally in 2017 in the growing seasons. The shrub layer was divided into a low and a high sub-layer in the 48 × 48 m monitoring plot.

Specimens which were higher than 1.0 m were categorized as high shrubs. Lower specimens were categorized as low shrubs. The term "dominant woody species" is used to refer to the *Acer campestre* L. (field maple), *Acer tataricum* L. (Tatar maple) and *Cornus mas* L. (European cornel) that play a key role in the understory. Several size variables of each high shrub specimen in the sampling plot were determined. Plant height (H) was measured with a scaled pole and shoot diameter (DSH) at 5.0 cm above the ground with a digital caliper. Total basal area of the high shrub layer and of high shrub species was calculated based on the shoot diameter values (BA, $m^2$ $ha^{-1}$). Mean cover of high shrub species and actual foliage cover of high shrub layer were calculated in $m^2$ and in the latter case expressed in percentage of the permanent sampling area. The foliage map was built in a GIS environment (ESRI, 1999). Based on the digitized map we estimated the foliage cover values with the Spatial Analysis Tools - Calculate Area function of the GIS. Statistical regression analysis was performed using the PAST statistical software and significant differences for all statistical tests were evaluated at the level of $*P < 0.05$; $**P \leq 0.01$. There was no significant correlation found between the test variables at $^{n.s.}P \geq 0.05$.

## RESULTS AND DISCUSSION

Mean height and diameter, basal area of shrub species and of shrub layer, foliage cover and other importance values of understory shrub layer are given in Table 1 and in Table 2. Mean H of dominant woody species in the shrub layer increased considerably after the start of the oak decline; these species reached maximum below 3.0 m in height before the oak decline and were growing suddenly after 1982 and were measured between 5.3-8.7 m in height to 2017. Mean H of the co-dominant shrubs increased from 1.8 m to 2.4 m until 1997, after which it started to decrease again. Mean DSH of these species increased from 1.5 cm to 2.9 cm; however, after 1993, the mean values started to decrease. BA of the understory was only 0.005 $m^2$ $ha^{-1}$. After the decline, already in 1982, a considerably increase in the high shrub layer's BA was found, and this continued in the following observed years. The biggest total BA was recorded in the second last measuring with 11.66 $m^2 \cdot ha^{-1}$. The rate of maples species and *C. mas* BA together in the total BA was higher than 89.0%.

Table 1. Long-term tendency of the mean size values (±SD) in the high shrub layer.

| year | height (m) | | | | diameter (cm) | | | |
|---|---|---|---|---|---|---|---|---|
| | *A. camp.* | *A. tatar.* | *C. mas* | co-dom. shrubs | *A. camp.* | *A. tatar.* | *C. mas* | co-dom. shrubs |
| 1972 | 2.29 | 2.68 | 2.36 | 1.75 | 2.60 | 2.41 | 2.45 | 1.48 |
| 1982 | 4.83 | 3.43 | 3.64 | 2.21 | 5.20 | 3.39 | 3.95 | 1.91 |
| 1988 | 4.85 | 3.52 | 3.69 | 2.25 | 6.11 | 3.57 | 4.44 | 2.36 |
| 1993 | 5.20 | 3.37 | 3.81 | 2.34 | 6.63 | 4.69 | 5.68 | 2.92 |
| 1997 | 5.21 | 3.75 | 3.87 | 2.37 | 6.83 | 4.63 | 4.89 | 2.46 |
| 2002 | 5.88 | 4.22 | 4.66 | 2.14 | 8.61 | 5.36 | 6.43 | 2.33 |
| 2007 | 8.23 | 4.92 | 4.85 | 1.96 | 11.03 | 6.45 | 7.82 | 2.19 |
| 2012 | 7.60 | 5.50 | 5.37 | 1.82 | 10.63 | 7.4 | 7.50 | 1.94 |
| 2017 | 8.74 | 5.31 | 5.26 | 1.86 | 9.61 | 6.08 | 6.95 | 2.00 |
| mean±SD | 5.87 ±2.02 | 4.08 ±0.97 | 4.17 ±0.96 | 2.08 ±0.23 | 7.47 ±2.75 | 4.89 ±1.61 | 5.57 ±1.79 | 2.18 ±0.41 |

The regression analysis confirmed that significant positive relations were between mean H of maples species and decreasing oak tree density ($r$ = 0.77* and 0.72*) between 1972-2017. This relation between canopy tree density and mean H of *C. mas* ($r$ = 0.82**) and mean DSH of dominant woody species ($r$ = 0.84**, 0.80**, 0.84**) was stronger (Fig. 1. A, B). The relationship was non-significant between oak density and mean sizes of co-dominant shrub species ($r = 0.25^{n.s.}$ and $0.62^{n.s.}$).

Table 2. Long-term tendency of the mean cover, foliage canopy and basal area values (±SD) in the high shrub layer.

| year | mean cover ($m^2$) | | | foliage canopy (%) | basal area ($m^2$ $ha^{-1}$) | | | |
|---|---|---|---|---|---|---|---|---|
| | *A. camp.* | *A. tatar.* | *C. mas* | | *A. camp.* | *A. tatar.* | *C. mas* | high shrub layer |
| 1972 | 2.79 | 1.87 | 2.45 | 64.40 | $0.17^{-2}$ | $0.13^{-2}$ | $0.13^{-2}$ | $0.48^{-2}$ |
| 1982 | 4.06 | 3.19 | 4.14 | 85.30 | 1.85 | 0.30 | 0.90 | 3.13 |
| 1988 | 5.59 | 3.32 | 5.21 | 84.16 | 2.18 | 0.19 | 0.89 | 3.40 |
| 1993 | 6.88 | 4.47 | 7.93 | 74.00 | 1.97 | 0.28 | 0.91 | 3.49 |
| 1997 | 7.23 | 3.20 | 5.66 | 79.50 | 3.00 | 0.34 | 1.38 | 5.30 |
| 2002 | 6.22 | 5.58 | 7.18 | 67.50 | 4.19 | 0.42 | 1.54 | 6.85 |
| 2007 | 11.54 | 9.71 | 12.44 | 86.20 | 4.69 | 0.35 | 2.18 | 7.99 |
| 2012 | 6.12 | 4.29 | 6.39 | 61.48 | 6.35 | 0.57 | 3.92 | 11.66 |
| 2017 | 12.34 | 9.97 | 12.67 | 91.26 | 5.16 | 0.31 | 1.66 | 8.04 |
| mean±SD | 6.97 ±3.14 | 5.07 ±2.90 | 7.12 ±3.48 | 77.09 ±10.68 | 3.27 ±1.99 | 0.31 ±0.16 | 1.49 ±1.10 | 5.54 ±3.48 |

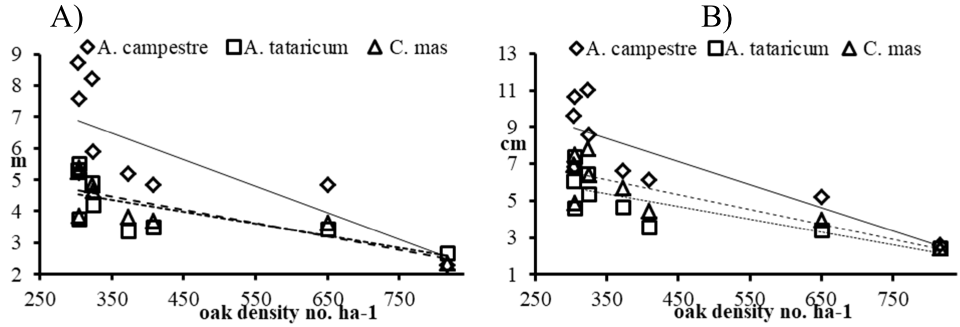


Figure 1. Relationship between oak tree density and (A) mean height, (B) mean diameter of the dominant woody species between 1972–2017. [*A. campestre* —. (A) $R^2 = 0.60$, $P < 0.05$; (B) $R^2 = 0.70$, $P \leq 0.01$; *A. tataricum* ···, (A) $R^2 = 0.51$, $P < 0.05$; (B) $R^2 = 0.64$, $P \leq 0.01$; *C. mas* - - - , (A) $R^2 = 0.68$, $P \leq 0.01$; (B) $R^2 = 0.70$, $P \leq 0.01$]

The analysis did show a significant relation for maples species ($r$ = 0.79*, 0.74*), for *E. verrucosus* ($r$ = 0.75*) and for high shrub community ($r$ = 0.77*) between BA values and decreasing oak tree density (Fig. 2. A). Over last 45 years; the association is non-significant for BA of *C. mas* ($r = 0.65^{n.s.}$). Low significant relationship are observed between mean cover of *A. campestre*, *C. mas* and oaks density ($r$ = 0.70* and 0.68*) (Fig. 2. B). Changes of mean cover of *A. tataricum* ($r = 0.57^{n.s.}$), co-dominant shrubs ($r = 0.58^{n.s.}$), foliage cover of the high shrub layer ($r = 0.20^{n.s.}$) and oak decline for the long-term study are found to have a non-significant relationship. According to Röhrig and Ulrich (1991) *A. campestre* is a relatively drought tolerant species. On the other hand, maples have got "Oskar"-strategy (Silvertown, 1982). Maples typically develop a “sit-and-wait” strategy so they wait for example for the canopy decline events. Oaks cannot successfully compete with these species (McDonald *et al*., 2002, Zaczek *et al*., 2002). Our results support these statements, because in our site maples showed a significant increase in size and foliage cover after the oak decline. In the upland oak forest of USA the total basal area in the understorey was substantially higher in 2002 than in 1934, increasing from 0.9 to 3.6 $m^2 \cdot ha^{-1}$, while the density of most oaks and shortleaf pines in the canopy decreased (Chapman *et al*., 2006). We found similar tendency in Síkfőkút. Our findings confirm that long-term DSH changes of the dominant woody species and size values of *A. campestre* most significantly associated with oak decline (Fig. 1., 2.).

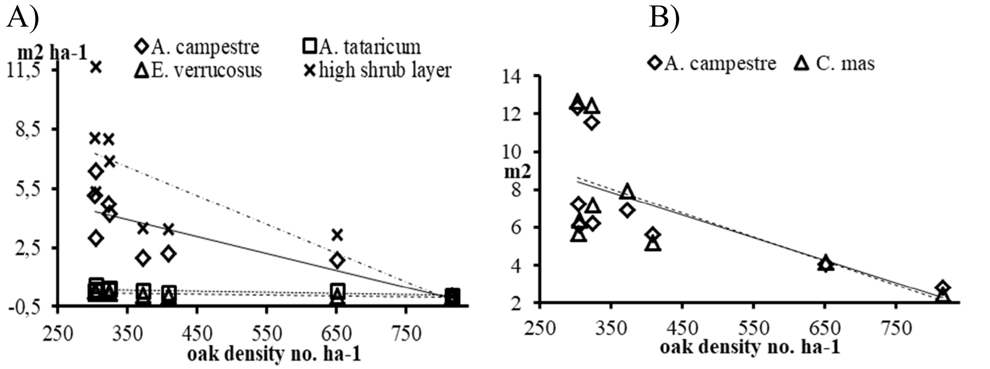


Figure 2. Relationship between oak tree density and (A) basal area, (B) foliage cover changes in the shrub layer between 1972–2017. [*A. campestre* —. (A) $R^2$ = 0.63, $P < 0.05$; (B) $R^2$ = 0.49, $P < 0.05$; *A. tataricum* ···, (A) $R^2$ = 0.55, $P < 0.05$; *E. verrucosus* - - - , (A) $R^2$ = 0.56, $P < 0.05$; high shrub layer - • - • - (A) $R^2$ = 0.60, $P < 0.05$; *C. mas* - - - , (B) $R^2$ = 0.46, $P < 0.05$]

## CONCLUSION

Our study suggests that (1) dominant woody species growth was significantly affected by serious oak decline; this association was higher to the DSH values of these species. (2) Decreasing density of canopy oak trees was significantly affected on the long-term trend of basal area of maples species and *E. verrucosus*. The association was similar to the high shrub community. (3) A significant relationship between mean cover of *A. campestre* and *C. mas* and oak tree density was observed for the 45 years in the studied forest stand. Overall, the shrub layer condition and growth dynamics consistently associated with canopy oak mortality.

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