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Canopy recovery of pedunculate oak, Turkey oak and beech trees after severe defoliation by gypsy moth (*Lymantria dispar*): Case study from Western Hungary

Regenerácia olistenia duba letného, duba cerového a buka lesného po silnej defoliácii mníškou veľkohlavou (*Lymantria dispar*): Prípadová štúdia zo západného Maďarska

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Abstract

We investigated the canopy recovery of 3 tree species (pedunculate oak, Turkey oak, European beech) at two locations in the Veszprém county (Western Hungary) after severe defoliation by gypsy moth caterpillars in the spring of 2005. The Turkey oak has evidently the best recovery potential, and it almost completely replaced the lost foliage in 4 months. The pedunculate oak and beech needed 2 years to reach the same level of recovery. The pedunculate oak suffered from a heavy infection of *Microsphaera alphitoides* after defoliation and it probably slowed down its recovery. Neither the presence of *Agrilus biguttatus* in the oak plot nor the appearance of *Agrilus viridis* in the beech plot was observed during the study period. Population density of the buprestid *Coraebus floerentinus* showed a considerable increase in the oak plot, but remained under the damage level. Neither other harmful appearance of other pests nor significant tree mortality were observed within 4 years from the defoliation. These results provide information for the evaluation of longer term influences of the gypsy moth defoliation and may support the decisions concerning pest control.

Key words: defoliation; gypsy moth; oak mildew; tree mortality; Hungary

Abstrakt

Hodnotili sme regeneráciu olistenia troch druhov drevín (duba letného, duba cerového a buka lesného) na dvoch lokalitách v regióne Vezprém (Maďarsko) v období po intenzívnej defoliácii mníškou veľkohlavou, ku ktorej došlo na jar roku 2005. Dub cerový mal najlepšiu regeneračnú schopnosť a takmer kompletne obnovil olistenie v priebehu štyroch mesiacov. Dub letný a buk lesný potrebovali na dosiahnutie tej istej miery regenerácie dva roky. Dub letný trpel v sledovanom období infekciou *Microsphaera alphitoides*, čo zrejme spomalilo regeneráciu. V dubovom poraste nebola pozorovaná prítomnosť *Agrilus biguttatus* a v bukovom poraste *Agrilus viridis*, ktoré môžu ovplyvniť proces regenerácie. V dubovom poraste značne vzrástla početnosť *Coraebus floerentinus*, avšak zostala po úrovňou, pri ktorej môže dôjsť k vážnejšiemu poškodeniu. V období štyroch rokov po defoliácii nebola zaznamenaná prítomnosť žiadnych ďalších škodlivých činiteľov ani zvýšená mortalita stromov. Prezentované výsledky poskytujú informácie o dlhodobom vplyve defoliácie mníškou veľkohlavou a môžu tak podporiť rozhodovanie o realizácii ochranných opatrení.

Kľúčové slová: defoliácia; mníška veľkohlavá; drobnomúčka dubová; mortalita stromov; Maďarsko

1. Introduction

Gypsy moth (*Lymantria dispar*) is an extremely polyphagous and exceptionally important forest pest in many European and Asian countries, North-Africa, and also in the United States (McManus 1978; McManus & Csóka 2007; Pernek et al. 2008; Zúbrik and Novotný 1996; Zúbrik et al. 2013). There are good reasons to assume that pest`s importance will increase even further in the near future. Vanhanen et al. (2007) forecasted significant northward shift of its boundary for different climate change scenarios. There are several predictions for increasing damage area due to climate change (Leskó et al. 1994; Csóka 1997; Csóka & Hirka 2009; Hlásny & Turčáni 2009; Hirka et al. 2011; Hlásny et al. 2011; Klapwijk et al. 2013; Hlásny et al. 2015).

The gypsy moth is undoubtedly the most important forest pest in Hungary. The outbreaks occur in a ca. 10-year interval. The severe and long lasting drought is regularly considered as the main triggering factor of the gypsy moth outbreaks (Leskó et al. 1994; Csóka 1997; Csóka and Hirka 2009). After a long and dry period (2000–2003) Hungary experienced an exceptionally severe outbreak that swept through the country between 2003 and 2006. In the peak year 2005, the damage was reported from 212,000 hectares (Csóka & Hirka 2009). The Veszprém county (West Hun-

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gary, north of the lake Balaton) is a "traditional" centre and often a starting point of gypsy moth outbreaks, mainly due to high share of forests (particularly oaks) and the favourable climatic conditions. The primary food plant of the gypsy moth in Hungary is Turkey oak (*Quercus cerris*) and pedunculate oak (*Quercus robur*), though many other broadleaved tree species can be damaged. Beech stands are defoliated less often, but in 2005 and 2006 even montane beech stands suffered from damage due to vertical expansion (appearance of damage at higher elevations) of the outbreak (Csóka & Hirka 2009).

The severe defoliation may have significant ecological and economical impact on forests. Both increment loss (Varga 1964; Leskó 1986; Muzika & Liebhold 1999) and tree mortality (Szontagh 1985, 1987; Davidson et al. 1999; McManus & Csóka 2007) are reported as possible consequences of defoliation. The defoliation events are often followed by mass occurrence of other (mainly xlophagous) insects, and pathogens. These organisms (often called "secondary pests/pathogens") are able either to slow down or prevent the full recovery. Sometimes, even significant tree mortality in the earlier defoliated stands might occur (Szontagh 1985; McManus & Csóka 2007; Csóka & Hirka 2009).

In this study we investigated the recovery processes of sample trees during 4 years at two experimental plots (one beech and one pedunculate oak mixed with turkey oak) after defoliation by gypsy moth in late spring 2005. We also investigated the influence of other harmful organisms acting either in the same time or following the defoliation by the gypsy moth.

2. Material and methods

The investigations were made at two experimental plots (Table 1, Fig. 1) in Veszprém county. Both plots are located in the core area of gypsy moth outbreaks.

Both plots have irregular shape. Area of the oak plot was ca. 0.2 ha, and area of the beech plot was ca. 0.3 ha. We visited the plots once in 2004 (mid–September) and then twice a year (late May and mid–September) between 2005 and 2009. No information on the level of defoliation prior to autumn 2004 was available. All sample trees were classified in one of the following social classes during each autumn visit: 1 – outstanding; 2 – dominant; 3 – supressed from side (narrow crown supressed from sides, but the top still not closed); 4 – supressed from the top (top of the crown is closed by other trees).

Table 1. Main information form the two experimental plots involved in the study.

Plot	Coordinates	Elevation [m a.s.l.]	Age [years] Average height [m] Average diameter [cm]*	Number of sample trees [autumn 2004]
Magyargencs 21C	N47°24' 24.9" E17° 14' 59.8"	~ 135	46 years 16 m 25 cm	*Quercus robur:* 56 *Quercus cerris:* 20
Ugod 31A	N47° 17' 32.0" E17° 39' 45.9"	~ 350	96 years 40 m 40 cm	*Fagus sylvatica:* 87

*stand data refer to year 2004.

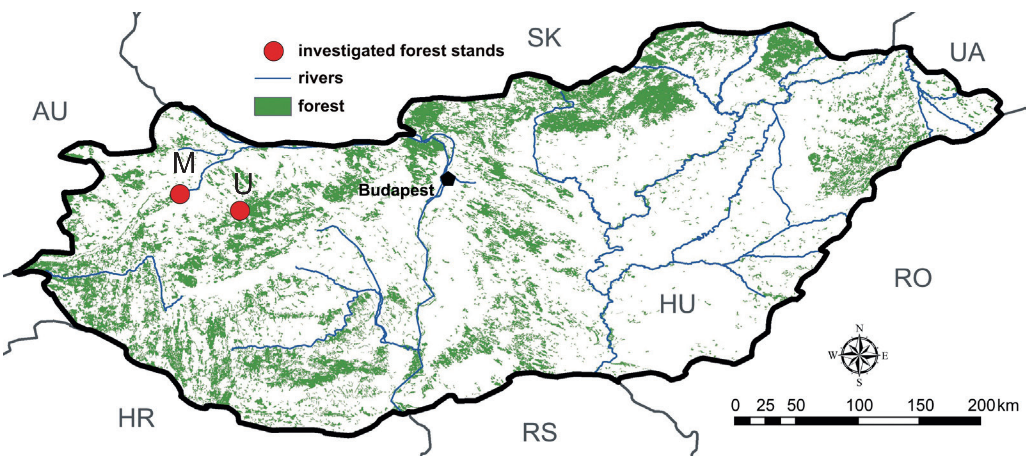

Fig. 1. Locations of the two experimental plots in Hungary (M = Magyargencs; U = Ugod).

The high density of egg (>1,000/ha) masses observed in autumn 2004 at both locations predicted considerable defoliation in spring 2005. Defoliation levels (at 10% accuracy) were estimated and recorded for all sample trees during all visits (11) using binoculars. Presence and intensity of other significant damage symptoms were recorded as well. The original intention was to score the presence of *Agrilus biguttatus* by counting the number of typical "bleeding spots" on the stems at the entrance points of the young larvae boring into the stem. However, this survey could not be done because the pest – contrary to our expectations – was not occuring in the oak plot.

Abundance of *Coraebus florentinus* was scored by counting the branches killed by its larvae. These branches are easily detectable in the parts tree crown exposed to the sunlight and therefore their fading and drying can't be explained by the lack of light. We classified the *Microsphaera alphitoides* infection into two classes: 1 – the mildew cover is present on more than 50% of the leaves of the given tree, 2 – the mildew cover is present on less than 50% of the leaves of the given tree. Dead sample trees (if any) in the actual year were recorded during the autumn census.

To evaluate the significance of differences between tree species and social classes we used the Wilcoxon test. This is a non-parametric version of the t-test. The test was used because it allows (unlike the t-test) analysing data with non-normal distribution, which was the case of our data. Moreover, the test is not sensitive to the presence of outlier data.

3. Results and discussion

3.1. Canopy recovery of the investigated tree species

The p-values obtained by the Wilcoxon test for pairwise comparison (for period from autumn 2004 until autumn 2009) of the 3 tree species are given in Table 2 and the p-values for both tree species and social classes are in Table 3. Asterisks are used to indicate the statistically significant differences between the examined pairs at different levels.

Table 2. P-values of the Wilcoxon test between the defoliation of 3 tree species during the period from autumn 2004 until autumn 2009; significance levels: .= $p < 0.1$; *= $p < 0.05$.

	QR	QC	FS
QR	—	0.05.	0.79
QC	—	—	0.02*
FS	—	—	—

Species codes: QR – pedunculate oak, QC – Turkey oak, FS – beech.

While in autumn 2004 we recorded low level defoliation (below 10% in average) on oak sample trees, in late May 2005 every sample tree (both pedunculated and Turkey oaks) suffered from 100% defoliation in each social class (Fig. 2a,b). The totally defoliated trees started to recover their foliage after almost 3 weeks and reached ca. 50% canopy density by late June and total foliage by mid-July. The nearly 3 weeks of leafless period were far enough to kill all caterpillars due to starvation (together with NPV infection). The outbreak collapsed at both locations, but the reasons were different. In Magyargencs (oak plot), the main reason was the lack of food while in Ugod (beech plot), NPV infection played the major role. These two main types of mortality could be distinguished relatively easily. While the larvae dying of hunger were found mainly at the base of the trees, occasionally forming several centimetres thick layer, most of the virus infected larvae were hanging on the stems and were liquefying. Although we did not make any quantitative survey of parazitoid insects, it was evident that parazitoids (particularly the tachinid flies) played a significant role at both locations.

The population density dropped down dramatically at both places, no egg masses were detected during the autumn inspection in 2005.

Table 3. P-values of the Wilcoxon test between the defoliation of 3 tree species and social classes during the period from autumn 2004 until autumn 2009; significance levels: .= $p < 0.1$; *= $p < 0.05$.

	QR1	QR2	QR3	QC1	QC2	QC3	FS1	FS2	FS3	FS4
QR1		0.06.	0.75	0.7	—	—	0.81	—	—	—
QR2			0.45	—	0.002**	—	—	0.03*	—	—
QR3					—	0.13	—	—	1	—
QC1					0.75	0.13	0.94	—	—	—
QC2						0.07.	—	0.33	—	—
QC3							—	—	0.02*	—
FS1								0.71	0.44	0.02*
FS2									0.72	0.01*
FS3										0.04*
FS4										

Codes: QR – pedunculate oak, QC – Turkey oak, FS – beech, 1–4 indicates a social class.

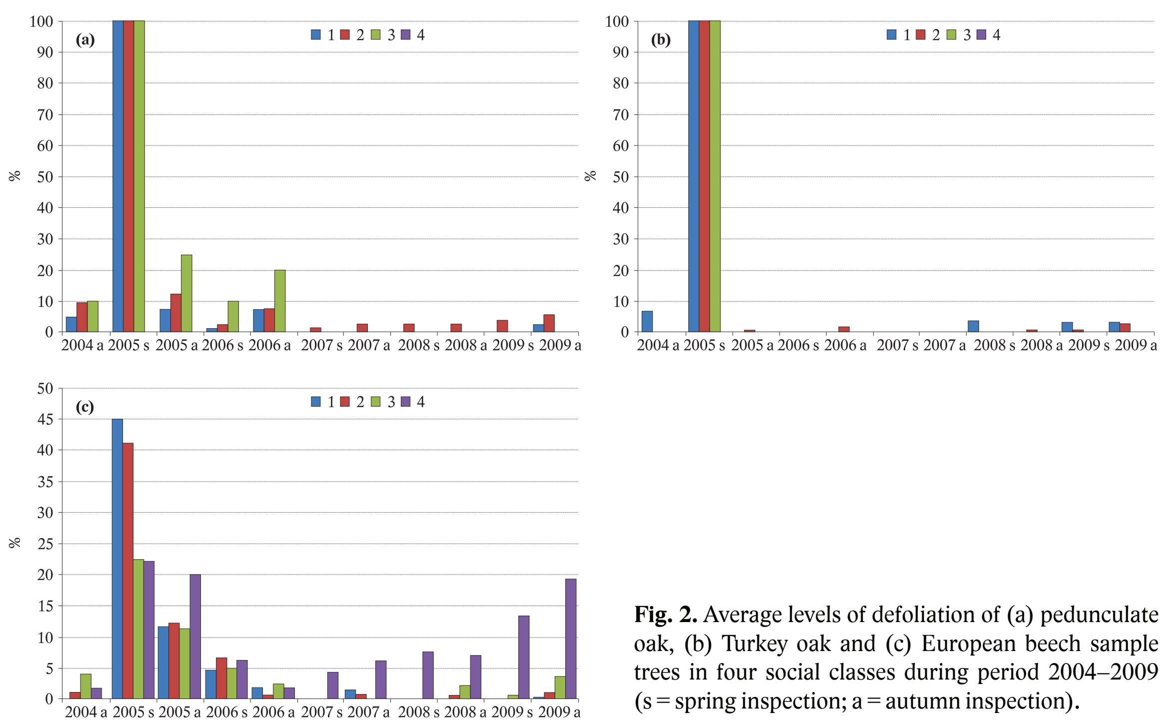

Fig. 2. Average levels of defoliation of (a) pedunculate oak, (b) Turkey oak and (c) European beech sample trees in four social classes during period 2004–2009 (s = spring inspection; a = autumn inspection).

Pedunculate oaks exhibited considerable foliage deficiency even in autumn 2006. These foliage losses were reciprocal with the social classes. In other words, the sample trees in lower social classes recovered slower and less completely in 2006 than sample trees in the higher social classes. By spring 2007 the recovery was completed, but minor foliage loss remained until the end of our investigation (autumn 2009), particularly on the dominant trees. At the same time, Turkey oak sample trees recovered almost completely within 4 months after the total defoliation (by autumn 2005) in all social classes and almost no foliage losses were detected in the next 4 years in any social class. The average defoliation in all social classes and all years was near to 5%.

After the negligible defoliation in the beech plot in autumn 2004, we detected highly increased defoliation level in spring 2005 (Fig. 2c). However, these levels were far lower than the defoliation in the oak plot, where 100% defoliation was recorded in each social class in May 2005. This difference can likely be explained by two independent factors. The leaf mass on the almost 100 years old beeches (average height is close to 40 meters, the average breast height diameter is ca. 40 cm) probably satisfied and even exceeded the food demand of the caterpillars. The other reason might be that beech was flushing new compensatory shoots (unlike oaks) permanently, even when the caterpillars were still chewing on it. The highest defoliation level (45%) in spring 2005 was observed on the outstanding trees, followed by the dominant (41%) and then the supressed trees (23% and 22%). This level of defoliation is much less common on beech than on pedunculate and Turkey oak.

Even so, the foliage recovery was similar on outstanding/dominant/side-supressed trees (slightly above 10% foliage deficiency in autumn 2005) and lower on supressed trees (20%). The canopies recovered completely by spring 2007, when only the supressed trees had an average 4.2% loss of foliage. The temporal pattern of the canopy recovery of beech is slightly similar to that of the pedunculate oak and certainly slower and less complete than that of the Turkey oak. We assume that beech with the permanent replacement of the consumed foliage may lose more of its nutrient reserves (and therefore recovery potential) than oaks.

From autumn 2007 a moderately increasing level of defoliation was observed again, particularly on the supressed trees. This trend is probably due to the severe drought in 2007 and 2009. The tree mortality was rather low in the observation period, only one supressed tree died in autumn 2009 (1.2% mortality).

3.2. Damage agents following the defoliation

In addition to a slower recovery, strong powdery mildew (*Microsphaera alphitoides*) infestation was recorded on the pedunculate oaks in each year in all social classes. This infestation was strongest in the autumn 2005, but it remained considerably severe during the whole period ending in autumn 2009. All sample trees fell into class 1, thus more than 50% of leaves on each sample tree in each year was covered by mildew. The heavy infestation had been expected since powdery mildew is known to reach the epidemic level particularly after frost damage, drought and/or severe defoliation caused by insects (Szabó 2003). The relationship of defoliation and the powdery mildew infestation is also mentioned by Delatour (1983) and Thomas et al. (2002). It is noteworthy that heavy chronic mildew infestation appeared in almost all pedunculate oak stands defoliated by gypsy moth in spring 2005 in the vicinity of investigated stands.

The reflushing oak foliage after defoliation is much more susceptible to the powdery mildew infection than the original leaves. The heavy fungal infection may cause a newer defoliation. This is a synergistic effect of defoliation and powdery mildew infection (Marçais & Desprez-Loustau 2014). The heavy infestation can also prevent the lignification of young shoots and therefore make them more vulnerable to the winter frost. Contrary to the pedunculate oaks, no detectable powdery mildew infestation was recorded in any year, although sometimes even Turkey oak might have been infested in epidemic years (Szabó 2003). This heavy mildew infection can be an alternative partial explanation for the foliage deficiency persisting longer on pedunculated oaks than on Turkey oaks.

From 2006 to 2009 we recorded the presence of branches killed by *Coraebus floerentinus* (Buprestidae) on both oak species without identifying any significant preference for any of them. Branches killed by buprestid were found almost exclusively on the outstanding and dominant trees. The species usually has a 2 years life cycle (Muskovits & Hegyessy 2002; Koltay & Leskó 1991; Zúbrik et al. 2013). It is a termophilous species, it regularly benefits from droughts and insect defoliations (Koltay and Leskó 1991) and sometimes can cause a minor damage locally. It is assumed that favourable conditions may accelerate species development and can therefore have a 1 year life cycle. The ratio of trees attacked was 55% in 2006, 21% in 2007, 20% in 2008 and 29% in 2009. The average number of branches (1.0–1.5 m long and 2–4 cm in diameter) killed/attacked tree varied between 1.0 and 1.5 in the four year period (2006–2009). This level of damage is considered not to affect the canopy recovery significantly.

Contrary to our expectation, no considerable damage of *Agrilus biguttatus* (or any other *Agrilus* species) was observed on sample trees, although *A. biguttatus* (together with other congeneric species) is a frequent and well known "follower" of drought events and/or severe insect defoliations, causing significant and rapid tree mortality (Csóka & Kovács 2000). We found severe infestation of *A. biguttatus* in many other pedunculate oak stands in the Veszprém county after the defoliation in 2005.

No mortality of investigated trees was recorded during the observation period (neither pedunculate nor Turkey oak).

We previously assumed that the observed unusual defoliation would increase the risk of damage by xylophagous insects such as *Agrilus viridis* and *Taphrorychus bicolor,* since these species caused large scale and more severe damage on beech stands of the Zala county (SW Hungary) in 2003–2005, even without previous defoliation (Lakatos & Molnár 2009; Molnár et al. 2010). Our survey, however, has not revealed presence and damage of these species in the beech plot.

4. Conclusions

The directions and speed of processes following any gypsy moth defoliation are strongly dependent on many factors such as tree species, age, site conditions (including weather), stand structure, presence or absence of different pest and pathogen populations, etc. In this 5-year study we investigated the canopy recovery of three forest tree species (pedunculate oak, Turkey oak, beech) after a severe defoliation by gypsy moth in spring 2005, when the oaks experienced 100% defoliation independently from their social class and beeches experienced 22–45% defoliation in different social classes.

The Turkey oak evidently has the best recovery potential, and it almost totally replaced the lost foliage in 4 months. The pedunculate oak and beech needed 2 years to reach the same level of recovery. The pedunculate oak suffered from a heavy infection of powdery mildew that probably slowed down its recovery. In addition, no significant so-called "secondary" pest or pathogen was observed to occur at a damaging level. No mortality of oaks and only 1.2% mortality (1 supressed tree) of beech was recorded during the 5 years of the study. We, however, assume that this study can be thought of as a "lucky" case study, since no significant "damage-chain" appeared and hardly any mortality was recorded within a 4 year period after the severe defoliation. Therefore our results cannot provide a basis for wide generalization. In many cases severe defoliation is followed by harmful appearance of xylophagous insects, scale insects, etc. and even by mass mortality of the attacked trees. However, our results provide information for the evaluation of longer term influences of the gypsy moth defoliation and may support the decisions concerning pest control.

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