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Direct Effects of Carpophagous Insects on the Germination Ability and Early Abscission of Oak Acorns

György CSÓKA* – Anikó HIRKA

Department of Forest Protection, Forest Research Institute, Mátrafüred, Hungary

Abstract – Carpophagous insects play an important role in decreasing the viability of acorns in both direct and indirect ways. Therefore they significantly influence the reproductive potential of oaks. As a direct effect, their feeding on the embryo and on the cotyledons may prevent the germination of the acorn and on the other hand, their damage causes premature acorn abscission. During 3 years, 60 acorn samples from five oak species (Turkey oak – *Quercus cerris*, pedunculate oak – *Quercus robur*, sessile oak – *Quercus petraea*, downy oak – *Quercus pubescens*, red oak – *Quercus rubra*) have been investigated. The average rate of damage varied a lot between years, but was always significant (2000: 36%, 2001: 61%, 2002: 51%). The insects' influence causing premature acorn abscission was significant both for pedunculate and Turkey oaks. The premature acorn abscission was 34% of the total crop in 2000 for pedunculate oak (*Curculio* spp. 26%, *Cydia* spp. 2% and *Andricus quercuscalicis* 6%) and 39% in 2001 (*Curculio* spp. 14%, *Cydia* spp. 2%, *Andricus quercuscalicis* 13%, *Callirhytis glandium* 10%). In case of Turkey oak it was 29% in 2001 (*C. glandium* 16%, *Neuroterus saliens* 13%, and 12% in 2002 (*C. glandium* 10%, *N. saliens* 2%).

oaks / *Quercus*, / acorn / carpophagous insects / germination ability/ early abscission

Kivonat – A karpofág rovarok közvetlen hatása tölgymakkok csíraképességére és korai hullására. A karpofág rovarok közvetlenül és közvetve is egyaránt jelentős szerepet játszanak a tölgymakkok csíraképességének csökkenésében, ezáltal a tölgyek reprodukciós képességében. Közvetlen szerepük kettős, egyrészről a lárvák a makkokban a csíra és a sziklevelek megrágásával megakadályozzák a makkok kicsírázását, másrészt jelenlétük, a korai makkhullás révén lehetetlenné teszi a makkok teljes kifejlődését. 5 fafaj (cser, kocsányos tölgy, kocsánytalan tölgy, molyhos tölgy, vörös tölgy), összesen 60 mintájának vizsgálata alapján megállapítható, hogy 3 vizsgálati év alatt a rovarok által elpusztított makkok aránya változó, de jelentős volt (2000: 36%, 2001: 61%, 2002: 51%). Két év vizsgálatai alapján megállapítható, hogy a fejletlen makkok lehullását előidéző rovarfertőzés kocsányos tölgy és cser esetében is egyaránt jelentős lehet. Kocsányos tölgynél 2000-ben a teljes makktermés 34%-ában, 2001-ben pedig 39%-ában okoztak idő előtti makkhullást a karpofág rovarok. Cser esetében ez az arány 2001-ben 29%, 2002-ben pedig a 12% volt.

tölgyek / *Quercus* / tölgymakk / karpofág rovarok / csíraképesség / korai makkhullás

* Corresponding author: csokagy@erti.hu; H-3232 MÁTRAFÜRED, Pf. 2

1 INTRODUCTION

Oaks cover 32.4% (547, 547 ha) of the total forested area in Hungary and their share from the standing tree volume (38%) is even higher (ÁESZ 2002). Although the percentage of natural regeneration is increasing in some regions of the country, artificial regeneration still remains dominant.

To fulfil the acorn demand for artificial regeneration, collecting of at least 1,000 tons of acorns per year are needed in Hungary (Hirka 2003). The acorn crop of oaks (with exception of Turkey oak) fluctuates significantly from year to year with good crops only every 5-6 years and 1-2 medium crops within these periods. Based on these facts, each biotic and abiotic factor influencing the survival and germination ability of the acorn crop (e.g. carpophagous insects) has outstanding importance.

Only the specialist herbivore insects connected directly to acorns are considered as carpophagous in this study. According to recent studies, 19 species of carpophagous insects (6 acorn weevils, 4 acorn moths and 9 gall wasps) are recorded from acorns of oaks in Hungary. Only 5 of them (*Curculio glandium, Cydia splendana, Andricus quercuscalicis*, *Callirhytis glandium*, *Neuroterus saliens*) are widespread and abundant enough to have a significant influence on acorn viability, the other species being rather sporadic and less abundant (Hirka 2003). Their influence can either be direct or indirect. This study considers the direct effects only.

2 LITERATURE REVIEW

Numerous authors have dealt with carpophagous insects of oaks in Hungary during the 20th century concerning both their direct and indirect effects. Ujházy (1950) discussed the life history of several acorn insects and the possible methods of winter storage of acorns. Győrfi (1954) listed the insects damaging acorns with special regard to their life history and importance. Beginning from the 1950s Mátyás (1963, 1965) studied the abiotic factors influencing the acorn crop, but also paid attention to the biotic factors including all three main groups of carpophagous insects. Vicze (1965, 1966) studied the development of acorn weevils and the abscission periods of acorns infested by them. Bürgés (1973, 1990) dealt with the pests of sweet chestnut including several species damaging both chestnuts and acorns (acorn weevils and acorn moths). Later he published data concerning the damage by acorn insects specifically (Szemes - Bürgés 1999). Fodor (1986) reported on the experimental control methods applied in order to reduce the loss due to the acorn insects. Hirka - Csóka (2000, 2001, 2002a,b) studied in detail the direct, and more intensively, the indirect effects of carpophagous insects on germination ability of acorns. These investigations raised several new questions and unsolved problems.

3 AIM OF THE STUDY

One of the direct effects of carpophagous insects is the consumption of the embryo by the larvae or the damaging the cotyledons to such an extent which makes the germination and the development of the seedling impossible. The aim of our investigation was to asses the rate of damaged acorns in storage and to quantify the probability of the germination of damaged acorns. According to both Hungarian and foreign authors (Kiss 1928, Magyar 1931, Roth 1941, Oliver - Chapin 1984, Forrester 1990, Rolfs 1999, Branco et al 2002, Hirka 2003) acorns infested by carpophagous insects do not always lose their germination ability. A considerable percentage can keep germination ability and still be able to produce viable seedlings.

Another of direct effect is the premature abscission of the infested young acorns, however less apparent because the result is often hardly visible and certainly less spectacular than the emergence holes on the infested fully-grown acorns. Therefore this damage was often overlooked even if its impact was not negligible. In our investigation we also aimed to quantify the effect of different carpophagous insects on early acorn abscission and to obtain a temporal pattern of process of acorn falling within a year.

4 METHODS

4.1 Embryo damage assessment

Samples were taken in 3 years (2000-2001-2002) in late February, after ca. 4 months storage from acorns of 5 species of oaks (*Quercus cerris*, *Q. robur*, *Q. petraea*, *Q. pubescens*, *Q. rubra – Table 1*). The acorns were originally collected at different locations in Hungary (*Table 2*). The average number of acorns in the samples was 554, 535, 859 respectively in the consecutive years (2000, 2001, 2002). The acorns in the samples were divided into two groups, „intact" and „damaged" (acorns with emergence holes) and the ratio of insect damaged acorns was calculated. 100 randomly selected damaged acorns were taken from each sample and cut in order to record the embryo's condition (dead/alive).

Table 1. Distribution of acorn samples by species and year

Species/Year	2000	2001	2002
Q. cerris	10	0	9
Q. robur	2	13	8
Q. petraea	3	5	1
Q. pubescens	1	3	0
Q. rubra	1	2	2
Total:	17	23	20

4.2 Premature acorn abscission assessment

The role of different carpophagous insect species in early acorn abscission was investigated in 2000 and 2001 at Püspökladány on *Quercus robur* and in 2001 and 2002 at Mátrafüred on *Quercus cerris*. The falling acorns were collected using 1x1 m collecting baskets (2 baskets under each of 2 *Q. robur* trees at Püspökladány and 3 baskets under 1 *Q. cerris* at Mátrafüred). The baskets were emptied weekly. The acorns caught in the baskets were examined and dissected to detect the presence of the different carpophagous species. The different species could be distinguished with high accuracy. The typical asexual galls of *Andricus quercuscalicis* on the acorns can be identified easily. The grouped galls of *Callirhytis glandium* and *Neuroterus saliens* could be identified based on size of the chambers inside the acorns. Larvae of *Curculio* and *Cydia* can also be distinguished easily. If larvae were not present, their faeces and emergence holes helped the identification. Faeces of *Curculio* larvae are dust-like and their emergence holes are circular. Faeces of *Cydia* larvae are grainy and they leave the acorns through a flattened oval emergence hole.

Table 2. Geographical origin of the acorn samples

Origin/Year	2000	2001	2002
Great Plain			
Baktalórántháza	–	QR, QRU	QR, QRU
Fehérgyarmat	–	QR (2)	QR
Gyula	–	–	QR, QRU
Valkó	QC	QR	QC
Northern Medium Mountains			
Buják	-	–	QC
Dejtár	QC, QP	–	QC
Felsőtárkány	QP	–	–
Kál	QR	–	–
Kálló	–	–	QC
Mátrafüred	QC	QP	QC
Szokolya	–	QP	–
South Transdanubia			
Iharosberény	–	–	QR
Sellye	QR	QR (2)	–
Tarany	–	–	QC
Transdanubian Medium Mountains			
Bakonyszentlászló	QC	–	–
Balatonfüred	QPU	–	–
Budaörs	–	QPU	–
Devecser	QC	QR (4)	QR
Leányfalu	QP	–	–
Olaszfalu	QC	–	–
Pápa	QC, QRU	QR	–
Pilismarót	–	QP	QC
Süttő	QC	–	–
Szentendre	–	QP	–
Veszprém	–	QR, QP, QPU (2), QRU	QC, QR
West Transdanubia			
Ravazd	QC	–	–
Röjtökmuzsaj	–	–	QC, QR, QP
Sopron	QC	–	–
Szentgotthárd	–	QR	–
Szombathely	–	–	QR

Abbreviation of oak species: *QC = Q. cerris,*
QR = Q. robur,
QP = Q. petraea,
QPU = Q. pubescens,
QRU = Q. rubra

5 RESULTS AND DISCUSSION

5.1 Embryo viability in infested acorns

The infestation rate varied greatly between years, tree species, and locations. The average infestation rate for all investigated oak species was 23% in 2000 (17 samples - ranging from 8% to 47%), 11% in 2001 (23 samples - ranging from 4% to 24%) and 25% in 2002 (20 samples - ranging from 3% to 55%). For the year 2000, 64% of insect-infested acorns had still viable embryos. The ratio was 39% in 2001 and 49% in 2002 (*Figure 1*).

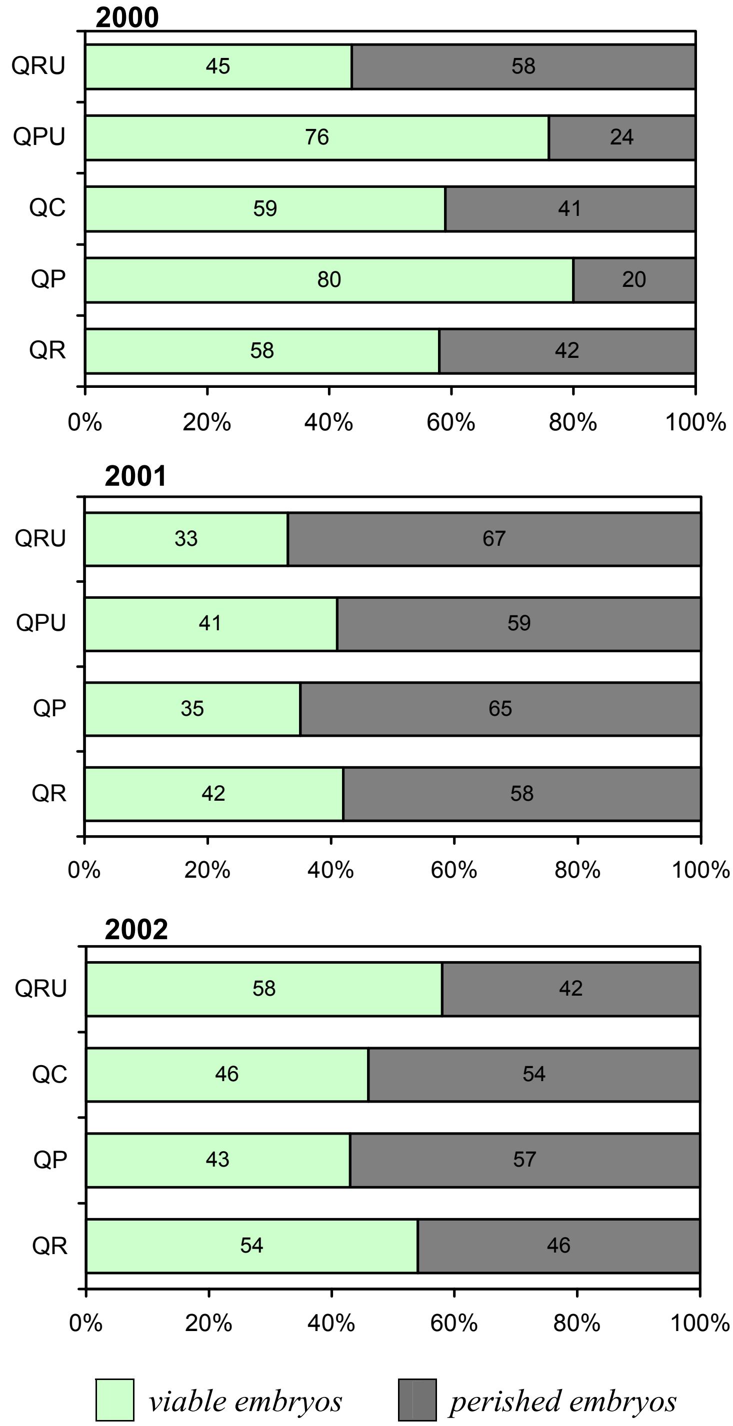

Figure 1. Ratio of viable and perished embryos in insect-infested acorns by different oak species in 2000-2001-2002 (for explanation of species abbreviations see Table 2)

In theory, the acorns with intact embryos could have been able to germinate. However, according to our other investigations, embryo mortality in infested acorns is more often caused by fungus penetrating the acorns via the emergence holes (to a lesser extent via the oviposition holes). So the acorns with intact embryos often loose their viability due to fungal infection (Hirka 2003). As this is not considered as a direct effect of carpophagous insects, it is not discussed further in this paper.

The ratio of acorns with perished embryos varied considerably between years: 36% in 2000, 61% in 2001 and 51% in 2002 (as an average of all oak species and all locations for the given year). Embryos of acorns with 2 or 3 emergence holes were mostly killed directly by feeding of larvae. However even in acorns with 3 emergence holes, embryos could sometimes survive. This does not mean of course that these acorns could produce vigorous seedlings, because the quantity of available nutrients of the wholly or partially consumed cotyledons is insufficient for the first period of the seedling's development.

It is worth mentioning that the number of emergence holes on an acorn is not a good indicator for the number of larvae that developed in the acorn (Hirka - Csóka 2004). During our investigations we found even an acorn from which 11 weevil larvae emerged through one single emergence hole.

It can be concluded that the feeding of carpophagous insect larvae does not necessarily destroy the embryo, and that insect infested acorns often retain their germination ability. Oliver - Chapin (1984) found that 24% of *Quercus virgiliana* acorns with emergence holes germinated. According to Forrester (1990) the intact acorns germinated at a twice higher ratio than the infested ones. In our other studies we found that the germination rate of intact *Quercus cerris* acorns was only 17% higher than that of the insect infested ones (Hirka 2003). Of course the viability of infested but still viable acorns strongly depends on acorn size and the number of larvae developed in it.

5.2 Early abscission of premature acorns

5.2.1 Quercus robur

Carpophagous insects damaged 59 % of the total crop in 2000 and 48% in 2001 (*Table 3*).

Table 3. Abscission of Q. robur acorns grouped by damaging factors at Püspökladány in the years 2000 and 2001

Damaging factors	*Q. robur* at Püspökladány 2000	2001
	%	
Callirhytis glandium	*0*	*10*
Andricus quercuscalicis	*6*	*13*
Curculio spp.	*49*	*19*
Cydia spp.	*4*	*6*
Carpophagous insects together	59	48
Fungal infection	4	4
Other abiotic factors	33	47
Intact, healthy acorns	4	1
Total (acorns/m^2)	261	175

The most significant change between 2000 and 2001 is the spectacular increase in the ratio of acorns infested by gall wasps. Two species (*Andricus quercuscalicis* and *Callirhytis glandium*) together infested 23% of the acorns, and in particular, the increase in the case of

Callirhytis is dramatic (from 0% to 10%). The ratio of acorns infested by *Curculio* decreased from 49% in 2000 to 19% in 2001.

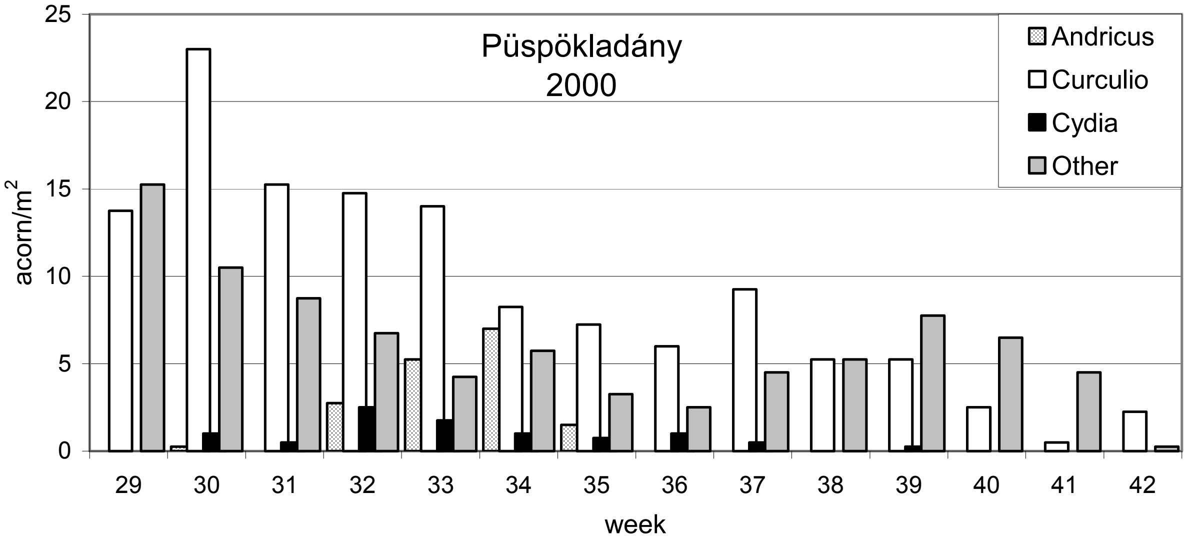

Figure 2. Abscission process of Quercus robur acorns at Püspökladány in 2000

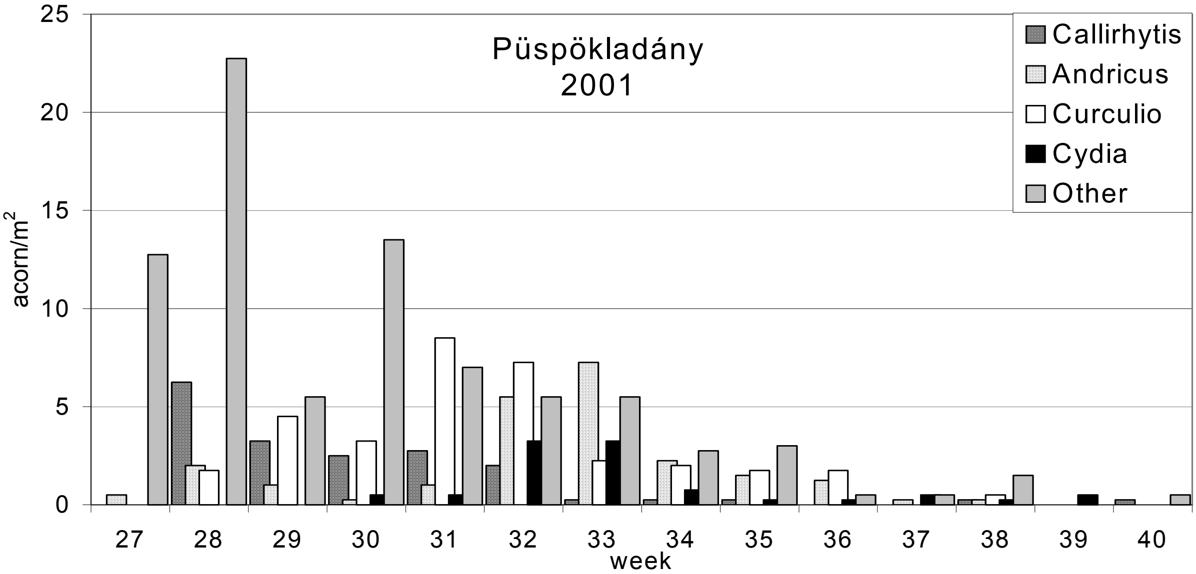

Figure 3. Abscission process of Quercus robur acorns at Püspökladány in 2001

Acorns falling until mid August were of small size (ca. half of the normal size) and these were not developed enough to be able to germinate. Acorns galled by *Andricus quercuscalicis* (6% in 2000 and 13% in 2001 of the total acorn crop) fell down within a relatively short period (a few weeks in August) in both years (*Figure 2,3*). Although these acorns were not small, the majority of them did not germinate. Acorns which fell due to the drought (33% in 2000 and 47% in 2001of the total crop) were small and not viable.

Vicze (1965) and Leskó (1991) found that insects play an important role in the early acorn abscission in the period from June to August. These observations were supported by the results of our investigations with the remark that drought played an outstanding role in both years by triggering premature acorn abscission.

5.2.2 Quercus cerris

Carpophagous insects in 2001 together infested 46% of the total crop in 2001 and 38% in 2002 (*Table 4*).

Table 4. Abscission of Q. cerris acorns grouped by damaging factors at Mátrafüred in the years 2001 and 2002

Damaging factors	*Q. cerris* at Mátrafüred 2001	2002
	%	
Neuroterus saliens	13	2
Callirhytis glandium	27	11 (9)*
Curculio spp.	3	18
Cydia spp.	1	6
Curculio spp.+ *Cydia* spp. **	0	1
Callirhytis gl.+ other larvae**	2	0
Carpophagous insects together	46	38
Fungal infection	4	8
Other abiotic factors	47	49
Intact, healthy acorns	3	5
Total (acorns/m^2)	888	749

(*previous year's *Callirhytis glandium,* **together in one acorn)

Two gall wasps, *Neuroterus saliens* and *Callirhytis glandium,* played a major role in the premature acorn abscission in 2001. While *Neuroterus* infested 13%, *Callirhytis* infested 27% of the total acorn crop, *Curculio* and *Cydia* played a relatively minor role in this year with 3% and 1% infestation rate. Their low prevalence is partially explained by the fact that the major early acorn abscission caused by the drought and the gall wasp species mentioned above decreased the number of available acorns dramatically, so *Curculio* and *Cydia* already did not have enough acorns in order to lay eggs and develop. In 2001 76% of the *Q. cerris* acorns fell down as small undeveloped acorns, unable to germinate.

These two gall wasp species damaged significantly decreased ratio of the crop in 2002. Contrary to this *Curculio* and *Cydia* larvae damaged an increased ratio of the acorns.

There were two distinct peaks in the abscission of acorns infested by *Callirhytis* in 2001 (*Figure 4*). The small undeveloped acorns fell first (16% of the total acorn crop and 60% of the *Callirhytis* infested acorns) in August-September. The fully grown *Callirhytis* infested acorns started to fall in late September and continued falling until the end of the falling period.

The temporal pattern of the abscission caused by the different factors in 2002 (*Figure 5*) differed slightly from the patterns of the previous year. The acorn abscission due to the drought (49% of the total acorn crop) peaked in July but continued with changing intensity until the end of the acorn falling period.

Acorns infested by *Neuroterus saliens* (2%) fell in June and July. The abscission of *Callirhytis* infested acorns can be divided in two periods. From late June to early August previous year's small acorns fell. These acorns remained on the tree until the following spring/early summer and were predated by birds (larvae were removed from the acorn leaving empty larval chambers in the cotyledons). Half of the current year's two year old acorns infested by *Callirhytis* fell as "half-size" acorns from mid August to late September and the fully grown infested acorns fell from mid September to mid October. 9/10 of the *Callirhytis* infested acorns did not develop to full size. 61% of the total acorn crop remained half-size or even smaller in 2002. 12% of the total acorn crop remained undeveloped due to some insect infestation (mainly the two gall wasp species).

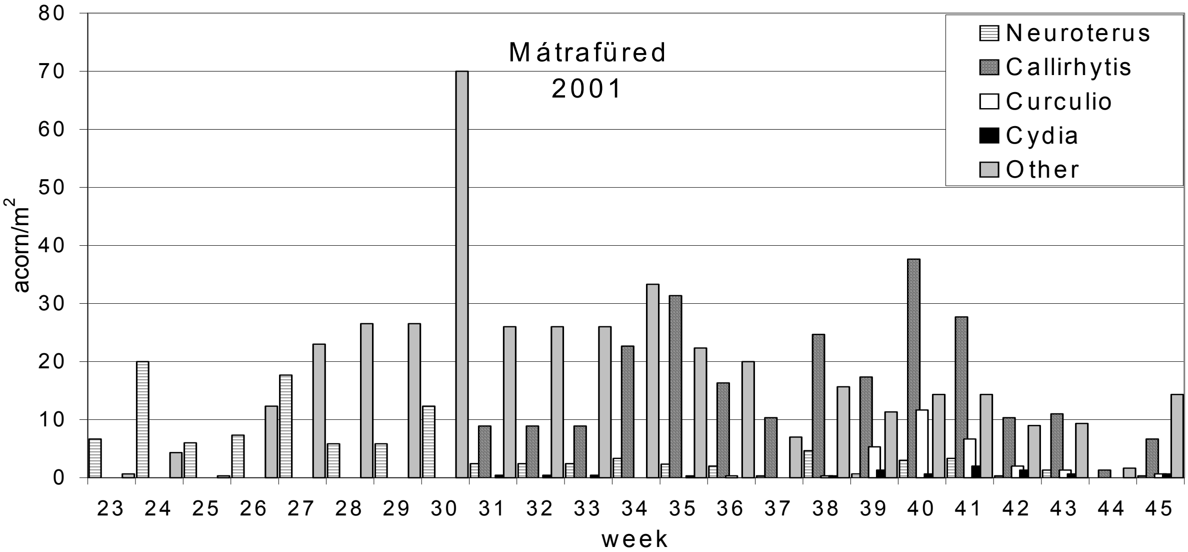

Figure 4. Abscission process of Quercus cerris acorns at Mátrafüred in 2001

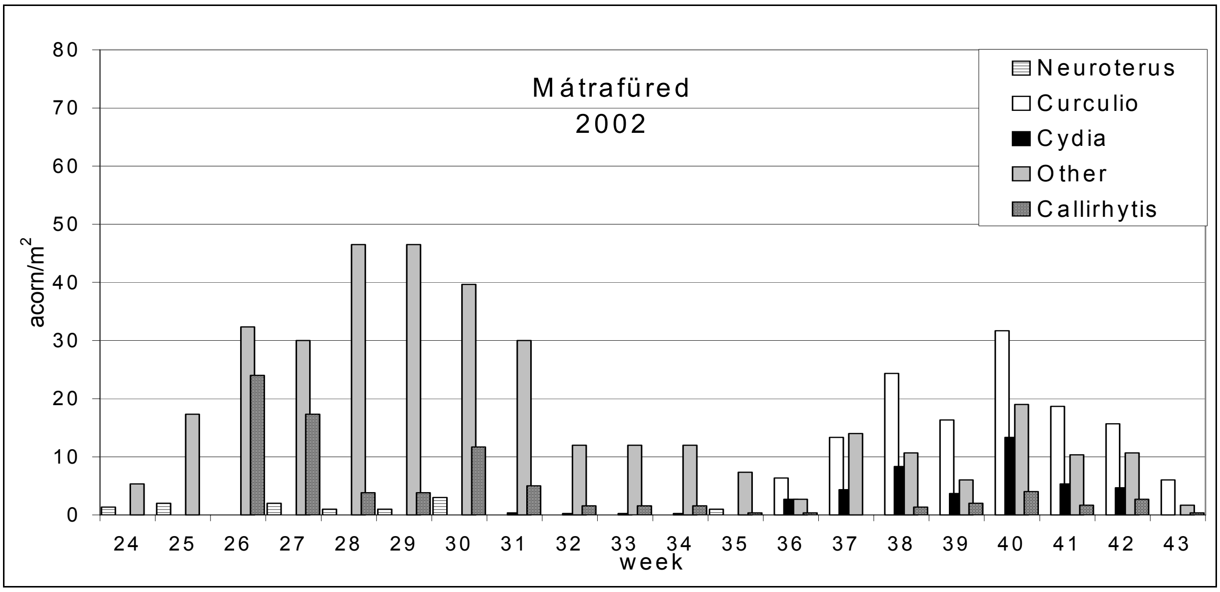

Figure 5. Abscission process of Quercus cerris acorns at Mátrafüred in 2002

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