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POLLINATORS (HYMENOPTERA: ACULEATA) OF *ADONIS VERNALIS* IN TRANSDANUBIA (HUNGARY)

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Abstract – We have to know the biology and ecology of species to help the effective conservation of protected species. Although the knowledge of pollination strategy is an important factor, our knowledge is poor even in the case of intensively studied species. It is necessary to know the plant-pollinator interactions and the requirements of effective gene flow for the maintenance of populations. The pollinators of *Adonis vernalis* L. (Ranunculaceae) were studied in 2017 and 2018 on the Csatár Hill near Veszprém, in Szentkirályszabadja, Csajág and Veszprém-Kádárta (Hungary). The number of collected *Lasioglossum* specimens was extremely high (433), followed by *Apis mellifera* (44), *Andrena* (23), and *Halictus* (23). We also collected specimens of *Bombus, Polistes, Vespula*, and *Osmia* genera. 5 males were also collected during the studies. It is probable that the males followed females (*A. vernalis* does not produce nectar) but they can function as pollinators thanks to their moving on the flowers. The visitation rate was the highest between 10–14 hours. Our new results can be useful to have more complete knowledge on the biology and ecology of *A. vernalis* and can help to develop the conservation strategy of the species.

Key words: *Andrena*, *Apis mellifera*, flower-visiting insects, *Lasioglossum*, pollen

INTRODUCTION

Adonis vernalis L. shows a declining tendency throughout its range (Anonymous 2000), therefore the knowledge of its biology and ecology is very important from a nature conservation aspect. Sexual reproduction has important genetic and evolutionary role as it helps the inter- and intrapopulation variability of individuals (Denisow *et al.* 2014). The effectiveness of pollination is a significant factor in the reproduction success of entomophilous species as both fructification rate and seed set depend on fertilization which is the result of pollination (Larson & Barrett 2000). The plant-pollinator interactions are influenced by many factors besides environmental ones (Denisow *et al.* 2014). In the temperate climate zone about 80% of plant species, including cultivated and wild species, are pollinated by insects (Strzałkowska *et al.* 2016).

In the case of polyandrious plant species – like *Adonis vernalis* – pollen and anthers can serve as forage for flower-visiting insects. These so called "pollen-flowers" are mainly visited by insects with short, simple mouthparts for feeding. The different insects (bugs, various Hymenoptera species, ants, etc.) feed in the flower chewing the anthers with their mouthparts and while they are moving the pollen sticks to their body they fertilize the pistil with pollen carried from another plant specimen. In the case of this strategy high pollen production is needed as a significant proportion of the produced pollen functions as forage. As a consequence it is not surprising that the ratio of pollens and ovules is high like in the case of wind pollinated species (Erbar & Leins 2013, Turcsányi 2001).

In beekeeping literature *A. vernalis* is mentioned as an important pollen producing plant. The demand of bees for nectar and pollen increases quickly in early spring (Denisow & Wrzesień 2006). As *A. vernalis* blooms early it is a significant pollen source for bees when the pollen is needed to feed the larvae to reach the proper family size.

In the case of *A. vernalis* biological and morphological mechanisms support dichogamy. Flowers show incomplete protogyny. The function of dichogamy depends on the activity of pollinators as well (Denisow *et al.* 2014). Stigma receptivity starts about one day before the anthers of the same flower start to shed pollen. Pollen viability is increasing during the life-span of the plant (Lloyd and Webb 1986). *A. vernalis* offers only pollen for pollinator insects, so its flowers have low energetic potential (Denisow *et al.* 2014). The results of Chittka *et al.* (1999) show that species without nectar production attract fewer insects than nectar producing species blooming in the same period. The species which cannot offer high caloric reward ensure pollen transfer with alternative strategies.

In the case of *A. vernalis*, the population structure and the structure of clumps are important factors to help gene flow. Flowers appear close to each other within the clump which can help to reduce the energy consumption of pollinators flying between the flowers. Flowers blooming close together can be visited rapidly after each other therefore pollen transfer is more probable. Theoretically in the case of one-ovuled pistils, only one pollen grain is needed to produce a single seed. Therefore there is no need for the repeated visitation of pollinators for efficient pollination (Denisow *et al.* 2014).

Denisow *et al.* (2014) found solitary bees (81.2%), *Bombus* species (9.6%), and *Apis mellifera* (8.2%) among Hymenopteran pollinators of *A. vernalis* populations (Table 1). They observed the following solitary bee species: *Osmia rufa* Linnaeus, 1758, *Andrena albicans* Müller, 1796, *A. cineraria* Linnaeus, 1758, *Andrena* sp., and *Halictus* sp., and the following bumblebees: *Bombus terrestris* Linnaeus, 1758, *B. pascuorum* Scopoli, 1763, and *B. lapidarius* Linnaeus, 1758. Their study showed that the visitation rate of bees was very low (1–2 insect visitors per hour per 50 m transect). They found it unexpected that the frequency of bumblebees was much lower than that of solitary bees. The low population size and density of bumblebees on the sample site was mentioned as a possible cause of this result.

This coincides with the results of Chmura *et al.* (2012). They recorded low pollinators number on *A. vernalis*. The low frequency of flower visitations on *Adonis* flowers is in relation with low early spring temperatures, as air temperature is usually below 15 °C during flowering. Some studies demonstrated that low temperature caused lower insect visitation rate (Denisow *et al.* 2014).

During the study of an *Adonis ramosa* Franch. population in Japan Kudo (1995) found that the activity of flower visiting insects was dependent on temperature, and low temperature limited its frequency. However, bumblebees are searching for forage at 5 °C or less, so they act as flower visitors in the flora of xerothermic grasslands in early spring (Chmura *et al.* 2013).

The results of Denisow & Wrzesień (2006) showed that apoid Hymenoptera species are the main pollinators of *A. vernalis*. Solitary bees represented 74.95%, *Apis mellifera* 21.3% and bumblebees 3.8% of all visitations (Table 1).

Table 1. Known pollinators of *Adonis vernalis*

Pollinators	Reference
Solitary bees (81.2%) *Bombus* species (9.6%) *Apis mellifera* (8.2%)	Denisow *et al.* (2014)
Solitary bees (74.95%) *Apis mellifera* (21.3%) *Bombus* species (3.8%)	Denisow & Wrzesień (2006)

MATERIAL AND METHODS

The study species

A. vernalis starts growing very early in spring and flowers already in mid April. It is one of the first flowering species of xerothermic grasslands (Jankowska-Błaszczuk 1988). Its bisexual flowers are solitary, terminal, actinomorphic, 2–3 cm long in diameter. The flowers have many typical entomophilous features. The flower consists of 5–6 green ovate sepals and 8–12 yellow, narrowly ovate petals. The petals are twice as long as the sepals. Nectaries are missing from the flower. The number of stamens and pistils is high. The ripening of the stamens and pistils of a flower happens at different times, so that self-fertilization is prevented (Denisow *et al.* 2014). The gynoecium consists of many 1-ovuled carpels. The carpels develop into achenes (Gostin 2009, Denisow *et al.* 2014). The elaiosomes on achenes attract ants, which helps fruit dispersal. Flowers open in sunlight and attract insects with their silky shining petals (Anonymous 2000). Flowers are opened in the early hours during only a 4-hour period (Denisow & Wrzesień 2006).

In our study we have observed the pollinators of this plant species. We compare our data with the results of other publications.

Counting pollinators

In 2017 we studied the pollinators of *A. vernalis* flowers in Szentkirályszabadja (Hungary) (Table 2). The insects were collected between 1 and 9 April through 20 hours in total (1–2 people collected simultaneously).

In 2018 the insects were collected between 14 April and 01 May in Szentkirályszabadja, on the Csatár Hill near Veszprém, in Csajág, and in Veszprém-Kádárta (Hungary) (Table 2). We studied the pollinators through 38 hours (1–3 people collected simultaneously).

Table 2. *Adonis vernalis* study sites

Settlement	N	E	Number of individuals	Habitat type	Study area (m^2)	Length of collection in hours (2017 and 2018)
Csajág	47.04738	18.18065	200–300	loess steppe	200	1
Szentkirályszabadja	47.035700	17.950291	~ 1000	slope steppe	2000	30
Veszprém	47.101894	17.853644	20,000–30,000	slope steppe	1200	21
Veszprém-Kádárta	47.108191	17.956996	~ 100	slope steppe	900	6

During the study the sample areas were observed continuously. The pollinators were collected in glasses every hour. So the presence of every pollinator was counted as a single flower visitation.

The collected specimens are preserved in the Rippl-Rónai Museum (Kaposvár, Hungary).

RESULTS

In 2017 the total number of flower visitations by Aculeata species was 60 (12 species), which means 3 visitations per hour on average (Table 3). In 2017 *Apis*

Table 3. Aculeata pollinators of *Adonis vernalis* in decreasing frequency (2017)

Species	Number of individuals	Sex	Time of flower visitation
Apis mellifera Linnaeus, 1758	20	worker	9:00–16:00
Lasioglossum xanthopus (Kirby, 1802)	10	♀	9:00–11:00, 12:00–14:00, 15:00–16:00
Lasioglossum obscuratum (Morawitz, 1876)	9	♀	9:00–14:00
Lasioglossum marginatum (Brullé, 1832)	6	5 ♀+1 worker	10:00–12:00, 14:00–15:00
Andrena lepida Schenck, 1859	4	♀	9:00–11:00, 15:00–16:00
Bombus terrestris (Linnaeus, 1758)	4	♀	10:00–13:00
Andrena flavipes Panzer, 1799	2	1 ♀+1 ♂	10:00–11:00, 13:00–14:00
Andrena gravida Imhoff, 1832	1	♀	15:00–16:00
Lasioglossum lineare (Schenck, 1869)	1	♀	13:00–14:00
Halictus rubicundus (Christ, 1791)	1	♀	13:00–14:00
Polistes nimpha (Christ, 1791)	1	♀	15:00–16:00
Vespula germanica (Fabricius, 1793)	1	♀	16:00–17:00
Total:	60		

mellifera was the most frequent pollinator of *A. vernalis* (25% of all flower visitations) (Table 3). If we evaluate our data according to genera (Table 4) most of the pollinators belonged to *Lasioglossum* genus (43%), followed by *Apis mellifera* (33%), *Andrena* (12%), and *Bombus* (7%) species. The ratio of *Halictus*, *Polistes*, and *Vespula* species was insignificant, each representing only 2%. The ratio of solitary bees was 60%, while the ratio of social bees was 40%.

Table 4. Aculeata pollinators (genus) of *Adonis vernalis* in decreasing frequency (2017)

Genus	Number of individuals	Ratio of all flower visitations (%)
Lasioglossum	26	43.3
Apis	20	33.3
Andrena	7	11.7
Bombus	4	6.7
Halictus	1	1.7
Polistes	1	1.7
Vespula	1	1.7

We recorded the most flower visitations between 10:00 and 11:00, followed by the period between 11:00 and12 (Table 5). *Apis mellifera* and *Lasioglossum* species visited the flowers between 9:00 and 16:00, while the other species had

Table 5. Temporal distribution of *Adonis vernalis* pollinators (2017, daylight saving time)

Time interval	Number of individuals	Ratio (%)
9:00–10:00	6	10,0
10:00–11:00	13	21.7
11:00–12:00	10	16.7
12:00–13:00	8	13.3
13:00–14:00	8	13.3
14:00–15:00	6	10.0
15:00–16:00	8	13.3
16:00–17:00	1	1.7
Total:	60	100

shorter visitation period (Table 3). The highest number of collected individuals per hour was 6. It was recorded on 9th April between 9 and 10. The lowest value was 2 collected individuals per hour: on 1st April between 14 and 15, and on 2nd April between 12:00 and 13:00 and 13:00 and 14:00. A male insect (*Andrena flavipes* Panzer, 1799) was also collected besides females and workers.

In 2018 we recorded 481 flower visitations (35 Aculeata species). It means 12.6 visitations per hour on average (Table 6). In 2018 *Lasioglossum xanthopus* (Kirby, 1802) was the most frequent pollinator of *A. vernalis*. This species represented 53% of all flower visitations (Table 6). According to genera (Table 7) most pollinators were member of the *Lasioglossum* genus (85%), followed by *Apis mellifera* (5%), *Halictus* (4.5%), *Andrena* (3%), and *Osmia* (1%) species. The ratio of *Nomada*, *Bombus*, *Polistes*, and *Chelostoma* species was insignificant. The ratio of solitary bees was 94.5%, while social species represented only 5.5%.

The most flower visitation was observed between 1200 and 13:00, followed by the period between 13:00 and 14:00. The *Lasioglossum* genus had the longest visitation period (9:00 and 16:00), followed by *Apis* and *Andrena* species (10:00 and 15:00) (Table 8). The highest number of individuals (67 specimens) was collected on 15th April between 10:00 and 11:00, 57 of them were *Lasioglossum xanthopus.* The lowest number of collected individuals (2) was: 16th April between 13:00 and 14:00, 20th April between 14 and 15, 22nd April between 13 and 14, and 23rd April between 11:00 and 12:00. Besides females and workers four males were also found on the flowers (*Andrena flavipes* Panzer, 1799*, Osmia aurulenta* (Panzer, 1799)*, Nomada bluethgeni* Stöckhert, 1943*, N. fucata* Panzer, 1798).

We found that 60% of the collected species has a wide range (Holarctic, Palearctic, Western Palearctic, and Eurosiberian). *Apis mellifera* is widespread on each continent (except Antarctica). 24% of the species has a Mediterranean range, while the remaining 14% occurs in other ranges (European, Central

Table 6. Aculeata pollinators of *Adonis vernalis* in decreasing frequency (2018)

Species	Number of individuals	Sex	Time interval of flower visitation
Lasioglossum xanthopus (Kirby, 1802)	257	256 ♀+1 worker	9:00–16:00
Lasioglossum marginatum (Brullé, 1832)	131	♀	9:00–16:00
Apis mellifera Linnaeus, 1758	24	2 ♀+22 worker	10:00–15:00
Halictus langobardicus Blüthgen, 1944	11	♀	10:00–14:00
Lasioglossum obscuratum (Morawitz, 1876)	7	♀	10:00–14:00
Andrena flavipes Panzer, 1799	5	4 ♀+1 ♂	10:00–11:00 and 12:00–15:00
Lasioglossum laevigatum (Kirby, 1802)	5	♀	12:00–15:00
Halictus scabiosae (Rossi, 1790)	4	♀	10:00–13:00
Andrena taraxaci Giraud, 1861	3	♀	11:00–13:00 and 14:00–15:00
Osmia bicolor (Schrank, 1781)	3	♀	10:00–12:00
Andrena gravida Imhoff, 1832	2	♀	10:00–11:00 and 14:00–15:00
Osmia aurulenta (Panzer, 1799)	2	1 ♀+1 ♂	10:00–11:00 and 12:00–13:00
Lasioglossum lativentre (Schenck, 1853)	2	1 ♀+1 worker	11:00–13:00
Halictus maculatus Smith, 1848	2	♀	10:00–11:00 and 12:00–13:00
Halictus kessleri Bramson, 1879	2	♀	10:00–12:00
Andrena varians (Kirby, 1802)	2	♀	11:00–12:00 and 13:00–14:00
Andrena bicolor Fabricius, 1775	1	♀	11:00–12:00
Andrena dorsata (Kirby, 1802)	1	♀	11:00–12:00
Nomada bluethgeni Stöckhert, 1943	1	♂	12:00–13:00
Nomada fucata Panzer, 1798	1	♂	10:00–11:00
Osmia rufa (Linnaeus, 1758)	1	♀	12:00–13:00
Osmia rufohirta Latreille, 1811	1	♀	13:00–14:00
Andrena minutula (Kirby, 1802)	1	♀	13:00–14:00
Andrena nitida (Müller, 1776)	1	♀	13:00–14:00
Bombus lapidarius (Linnaeus, 1758)	1	♀	11:00–12:00
Bombus terrestris (Linnaeus, 1758)	1	♀	12:00–13:00
Chelostoma marginatum Michener, 1938	1	♀	11:00–12:00
Halictus patellatus Morawitz, 1873	1	♀	10:00–11:00
Halictus quadricinctus (Fabricius, 1776)	1	♀	11:00–12:00
Halictus tetrazonius (Klug, 1817)	1	♀	10:00–11:00
Lasioglossum calceatum (Scopoli, 1763)	1	♀	13:00–14:00
Lasioglossum glabriusculum (Morawitz, 1872)	1	♀	11:00–12:00
Lasioglossum morio (Fabricius, 1793)	1	♀	11:00–12:00
Lasioglossum pauxillum (Schenck, 1853)	1	♀	14:00–15:00
Lasioglossum quadrinotatum (Kirby, 1802)	1	♀	11:00–12:00
Total:	481		

Table 7. Aculeata pollinators (genus) of *Adonis vernalis* in decreasing frequency (2018)

Genus	Number of individuals	Ratio of all flower visitations (%)
Lasioglossum	407	84.6
Apis	24	5.0
Halictus	22	4.6
Andrena	16	3.3
Osmia	7	1.5
Nomada	2	0.4
Bombus	2	0.4
Chelostoma	1	0.2

European, Euro-Turanian). 34% of the species is eremophilous, one of them is stenotopic while the others are eurytopic. The ratio of the most eurytopic species is 47%. The ratio of eurytopic and hilophilous species is only 19%. Most of the species are polilectic.

Table 8. Temporal distribution of *Adonis vernalis* pollinators (2018, daylight saving time)

Time	Number of individuals	Ratio (%)
9–10	5	1.0
10–11	96	20.0
11–12	73	15.2
12–13	117	24.3
13–14	115	24.0
14–15	65	13.5
15–16	10	2.0
total:	481	100

DISCUSSION

Only 4 of the 37 collected species were found in each sample area (*Apis mellifera, Halictus langobardicus, Lasioglossum marginatum, L. xanthopus*). 7 species occurred at two of the sample sites (*Andrena gravida, A. flavipes, A. taraxaci, Halictus maculatus, Lasioglossum lativentre, L. obscuratum, Osmia bicolor*). Most of the species were collected only from one of the sample areas.

The number of collected Hymenoptera species per hour was more than four times higher in 2018 than in 2017. One reason can be that early spring was cold in 2018 and pollinators were searching for food intensively after the long winter.

The higher number of sample sites in 2018 can be another cause of the higher number of collected individuals. In both years *Lasioglossum* species were the most frequent pollinators of *A. vernalis,* followed by *Apis mellifera.*

Visitation intensity was the highest between 12:00 and 14:00 in 2018, and between 10:00 and 12:00 in 2017. This can be also the results of the cool mornings in early spring in 2018.

The highest number of collected individuals per hour was significantly different in the two years (2017: 6 individuals, 2018: 67 individuals). In 2018 most of the collected individuals (57) were *Lasioglossum xanthopus* (Csatár Hill), so it is probable that the sampling happened during the swarm of the species.

Besides females and workers we found males in the flowers in both years. *Andrena flavipes* male was collected in 2017 and 2018 as well. The males visit the flowers only for nectar. Since *A. vernalis* does not produce nectar it is probable that these individuals followed the females and were not searching for food in the flowers. Males do not have special collecting hairs, so the probability of carrying pollen from a flower to another is lower. However the flowers of *A. vernalis* show incomplete protogyny, so male insects can also help the pollination as they can carry the pollen of the same plant to the stigma while moving in the flowers.

The ratio of solitary bees was higher in both years. *Apis mellifera* was the most frequent social bee species, followed by *Bombus* species. This result supports the observations of Denisow & Wrzesień (2006), but only partly meets the results of Denisow *et al.* (2014), as they collected more *Bombus* species than *Apis mellifera*. The following species from our list were collected by Denisow *et al.* (2014) as well: *Osmia rufa, Andrena* spp. (9 species), *Halictus* spp. (7 species), *Bombus terrestris*, and *B. lapidarius*. They collected *Andrena albicans* and *B. pascuorum* but we did not found these species. They find the low number of *Bombus* species surprising (9.6%), however it is much higher than that collected by us (0.5% in 2017, 7% in 2018). The visitation intensity of bees in our study in 2017 (3 individuals per hour) was close to their results (1–2 individuals per hour, but in 2018 we collected significantly more individuals on average (12.6 individuals per hour).

The most significant role of *A. vernalis* is producing forage (pollen) for insects. Its flowers open in early spring so they are especially valuable for apoid Hymenoptera species. The flowers of *A. vernalis* provide shelter for insects as well (we have seen mainly beetles sleeping and breeding in the flowers). Besides forage production these functions are very important for pollinators to maintain biodiversity.

The presence of pollinators is necessary to the successful propagation and seed production of *A. vernalis* but further studies are needed to clear the role of visiting insects in pollen transfer. The lack of pollinators can decrease the genetic viability of populations and with other factors increase the extinction risk of small *A. vernalis* populations. Early flowering is a valuable function so natural *A. vernalis* habitats should be preserved. This study focused on the pollinators of *A. vernalis* which helps the understanding of the biology and ecology of the species and supports the development of its conservation strategy.

* * *

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Összefoglaló: Ahhoz, hogy a védett fajok megőrzését elő tudjuk segíteni, ismernünk kell az adott faj biológiáját és ökológiáját. Bár a megporzási stratégia megismerése fontos tényező, még az intenzívebben kutatott fajok esetében sem rendelkezünk elegendő információval. A növény–pollinátor kapcsolat és a génáramlás követelményeinek feltárása feltétlenül szükséges a fajok meglévő populációinak fenntartásához. A megfigyeléseket *Adonis vernalis* L. (Ranunculaceae) virágokon 2017-ben és 2018-ban végeztük a Veszprém melletti Csatár-hegyen, Szentkirályszabadján, Csajágon és Veszprém-Kádártán (Magyarország). A két év megfigyeléseit összegezve kimagaslóan sok egyedet (433) gyűjtöttünk *Lasioglossum* fajokból, ezután az *Apis mellifera* (44), majd az *Andrena* (23) és a *Halictus* (23) nem képviselői következtek. További egyedeket találtunk *Bombus*, *Polistes*, *Vespula* és *Osmia* nemekből. A gyűjtések során 5 hímivarú rovart gyűjtöttünk, melyek csupán a nőstények után szállhattak a virágokra (az *A. vernalis* nem termel nektárt), de a virágban való mocorgásuk során megporzóként léphetnek fel. A legtöbb viráglátogatást naponta 10-14 óra között tapasztaltuk. Ezek az új eredmények hasznosak lehetnek az *A. vernalis* biológiájának és ökológiájának részletesebb megértéséhez, és hozzájárulhatnak a faj védelmi stratégiájának kidolgozásához.

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