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EFFECT OF WEATHER FRONTS ON MOSQUITO (DIPTERA: CULICIDAE) NUMBER BASED ON A 90-DAYS-LONG TRAPPING AND WEATHER OBSERVATION

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Abstract – Mosquitoes are the cause of summer nuisance and vectors of several pathogens. Their activity and abundance are determined by meteorological factors. We performed a 90-days-long mosquito trapping and parallel measuring of temperature, air pressure, and precipitation values in Felsőörs, Hungary. The aim of the study was to find a correlation between the changing weather conditions and the trapped mosquito numbers and the four most abundant mosquito species. A total of 1716 mosquito individuals was trapped, and 19 mosquito species were identified. *Aedes cinereus*, *Aedes vexans*, *Anopheles maculipennis*, *Culex pipiens* formed the 87% of the mosquito material. The regionally rare species, *Ochlerotatus excrutians* was also collected. The theoretical threshold of mosquito activity in the study was 11°C. Based on the multiple regression analyses, mean, maximum and minimum temperatures had a moderately strong positive effect, precipitation had a very weak positive effect and air pressure had a very weak negative effect on the number of caught mosquitoes. In the case of the four most abundant mosquito species, similar correlations were found. The statistical analysis of meteorological variables and mosquito numbers showed that higher mean daily temperatures 1 day prior to trapping had the most significant positive effect on mosquito numbers. Lower than average mosquito catches occurred mainly during or 1-2 days after the front passages, and the average mosquito catches generally were associated with front-free periods. It was concluded that weather fronts have a negative effect on mosquito activity.

Key words: anticyclones, abundance, trapping, activity, screening

Izvleček – VPLIV VREMENSKIH FRONT NA POJAVLJANJE KOMARJEV (DIPTERA: CULICIDAE) NA OSNOVI 90-DNEVNEGA MONITORINGA IN OPAZOVANJA VREMENA

Komarji so poletna nadloga in prenašalci več vrst patogenih organizmov. Njihovo aktivnost in številčnost določajo meteorološki dejavniki. V Felsőörsu na Madžarskem smo izvedli 90-dnevno vzorčenje komarjev in vzporedno merjenje temperature, zračnega tlaka in količine padavin. Cilj študije je bil ugotoviti korelacijo med spreminjajočimi se vremenskimi razmerami in številom ujetih komarjev. Skupno smo ujeli 1716 komarjev, ki pripadajo 19 vrstam. Vrste *Aedes cinereus*, *Aedes vexans*, *Anopheles maculipennis*, *Culex pipiens* so predstavljale 87 % ujetih osebkov. Poleg naštetih smo ujeli tudi regionalno redko vrsto, *Ochlerotatus exrutians*. Teoretični prag aktivnosti komarjev v študiji je bil 11 °C. Na podlagi večkratnih regresijskih analiz so imele srednje, najvišje in najnižje temperature zmerno močno pozitivno korelacijo, padavine zelo šibek pozitiven in zračni tlak zelo šibek negativen učinek na število ulovljenih komarjev. Statistična analiza meteoroloških spremenljivk in števila komarjev je pokazala, da so višje srednje dnevne temperature en dan pred ujetjem najbolj vplivale na število komarjev. Do številčno podpovprečnega ulova komarjev je v glavnem prišlo med ali 1-2 dni za vremenskimi frontami. Povprečni ulov komarjev je bil na splošno povezan z obdobji brez front. Ugotovljeno je bilo, da vremenske fronte negativno vplivajo na aktivnost komarjev.

KLJUČNE BESEDE: anticikloni, številčnost, vzorčenje, aktivnost, monitoring

Introduction

Mosquitoes are involved in the transmission of pathogens in almost the entire world (Cailly *et al.* 2012; Schaeffer *et al.* 2008). Mosquito-borne diseases occur not only in tropical-subtropical areas but also spread in temperate regions such as Central Europe. The spread of the vectors and the diseases were triggered by the increasingly hot summers of the recent decades (Ziegler *et al.* 2019). West Nile fever and the *Dirofilaria repens* nematode-caused dirofilariosis are autochthonous mosquito-borne diseases in present-day Hungary (Trájer *et al.* 2016a; Trájer *et al.* 2015a; Zittra *et al.* 2015). However, it should be noted that until the 1950s, malaria was also endemic in the country (Szénási *et al.* 2003). In addition to mosquito-borne diseases, mosquito-related disturbance can also have significant social impacts (Medlock et al., 2012). Mosquito species can cause notable nuisance both in recreation and detached house areas causing considerable revenue loss for the tourism sector. The mass emergence of such floodwater mosquitoes as *Aedes vexans* Meigen (1830) reduces life quality for inhabitants of infested areas. It also negatively affects the socio-economic conditions of the region (Schäfer and Lundström 2009). The protection against mosquito nuisance sometimes can require major financial expenses for the human populations of low-income regions (Snehalatha *et al.* 2003). It is known that mosquito abundance and diversity can be higher in the natural than in the artificial wetlands and wetland size has a positive effect on mosquito abundance (Schäfer *et al.* 2004). However, several important mosquito vector species – like the Asian tiger mosquito or the Yellow fever mosquito – prefer the artificial breeding habitats (Vijayakumar *et al.* 2014). On the other hand, anthropogenic effects can facilitate the colonization of areas with certain mosquito species. For example, river regulation and the construction of hydropower plants can modify the local mosquito fauna altering both mosquito abundance and diversity (Trájer *et al.* 2015b). Many artificial wetlands were constructed near human settlements in the last decades, thus raising the problem of these habitats being associated with mosquito nuisance.

Based on the above-described facts, it is important to clarify how the current weather conditions influence daily mosquito activity. It is well-known that weather influences insect populations (e.g., Sellers 1980). Mosquitoes are ectothermic animals, which means that they cannot regulate their own body temperature. Due to this circumstance, the physiological development and other biochemical processes of mosquitoes primarily depend on ambient temperature (Goindin *et al.* 2015). The abundance and activity of mosquitoes strongly depend on the actual weather conditions and climate (Schaeffer *et al.* 2008), and the alteration of ambient temperature directly affects their biting behaviour and fecundity (Martin *et al.* 2013). Temperature determines the development time of mosquito species in each development stage, as, e.g., in the case of *Aedes albopictus* Skuse (1894), it was proved (Delatte *et al.* 2009; Calado and Silva 2002). Modelling mosquito population dynamics, Walsh *et al.* (2004) concluded that average maximum temperature, the total number of heating degree-days, the total number of days with a minimum temperature below freezing during the winter months were predictive of seasonal abundance of mosquito populations. It should be noted that extremely hot temperatures decrease mosquito activity and survival (Reisen 1995). However, below the thermal death point, the growth rates of arthropod vector populations are positively correlated with elevated temperatures and densities are higher (Paz and Albersheim 2008; Charlwood *et al.* 2003). Increasing ambient temperatures shorten the interval between blood meals and raise the evolution speed of viral pathogens (Paz *et al.* 2013; Kilpatrick *et al.* 2008; Meyer *et al.* 1990; Ruiz et al. 2010). Even drought can cause mass mosquito emergences and the outbreak of mosquito-borne diseases (Shaman *et al.* 2005; Chase and Knight 2003). It can be concluded that increased temperature has been associated with the increased incidence of arboviral infection outbreaks, as it was, e.g., observed during its first Chikungunya epidemic in Italy (Tajudeen *et al.,* 2021).

Precipitation also has an important impact on mosquito abundance and activity. Higher winter and spring precipitation and the consequent increase of river runoff can explain the notable increase of mosquito abundance and viral mosquito-borne encephalitis incidence in floodplain areas (Wegbreit and Reisen 2000). Ndiaye *et al.* (2006) developed a model which describes the aggressiveness of *Aedes* mosquitoes following rainfall events. However, the effect of the different meteorological factors cannot be separated from each other. Due to this fact, the temporal variability of mosquito density and the incidence of the transmitted diseases are generally driven by the combination of several weather-related factors, especially rainfall, wind, temperature, and humidity (e.g., Smith *et al.* 2004). The effect is not coincident, a certain lag exists between the weather conditions and the transmission of mosquito-borne diseases (Chen *et al.* 2010). The effect of changing meteorological conditions on mosquito abundance could have some week latency. For example, Chuang *et al.* (2011) found that higher temperature in the current week and 2 weeks prior as well as higher precipitation 3 to 4 weeks before collection of host-seeking adult mosquitoes had positive influences on *Culex tarsalis* Coquillett (1896) abundance. Reisen *et al.* (2007) found that the temporal variation in the abundance of a vector mosquito, *Cx. tarsalis*, was linked significantly with coincident and antecedent changes of regional climate conditions. DeGaetano (2004) found out that monthly temperature and precipitation conditions accounted for between 40% to 50% of the variation in the average trapped number of mosquitoes. Similarly, Guoliang (2000) found that atmospheric temperature and rainfall both influence the density of mosquitoes although the correlation was much stronger in the case of temperature than precipitation. Qin *et al.* (2003) found that both temperature and humidity can influence mosquito density, but while the effect of temperature was found to be very strong, the influence of humidity seemed to be weak on mosquito abundance.

It is plausible that the most important meteorological factors of mosquito abundance can vary by mosquito species. For example, in the case of *Ae. albopictus* Yu *et al.* (2010) described that absolute humidity is the only factor influencing total mosquito density while some other factors like the daily sunshine duration and temperature are the factors influencing *Ae. albopictus* density. Zhou *et al.* (2010) concluded that temperature significantly influences mosquito abundance while rainfall does not. It is most plausible that temperature and precipitation influence in a different way and rhythm the population dynamics of mosquitoes. Ahumada et al. (2004) found that temperature and rain create cycles in the dynamics of the population of *Culex quinquefasciatus* Say (1823) in Hawaii. It should be noted that not only the climate or the weather, but human factors can strongly modify the mosquito abundance as well. Trawinski and Mackay (2010) found that *Culex pipiens* L. (1758) and *Culex restuans* Theobald (1901) population densities were positively correlated with human population density and housing unit density.

The modelling of the potential mosquito activity is not a theoretical problem because it can seriously impact the planning of mosquito-control activities. The timing, the location and the amount of pesticides and other biologically active agents applied is a very important issue. The use of personal protection techniques as mosquito repellents could have negative impacts on human health (Snehalatha *et al.* 2003; Sharma 2001). Integrated mosquito management contains several management components including surveillance, source reduction, prevention, biological control, repellents, traps, and pesticide-resistance management (Rose 2001). The development of such advanced techniques like remote sensing-based mapping of mosquito breeding habitats (Hassan and Onsi 2004), the associated health risk calculations and other control efforts can be expensive. While pesticides have several adverse effects on the ecosystems, such microbial agents as *Bacillus thuringiensis* var. *israelensis* (Bti) has become the object of most used selective techniques to control mosquitoes (Poulin 2012). A better understanding of the response of mosquito species to the changing weather conditions would help with the mitigation and pest control. The general annual abundance patterns of the native mosquito species are well known in Hungary due to the summary work of Tóth (2004). In contrast, the responses of mosquito activity to the day-scale changes of meteorological conditions were previously not studied in Hungary and this is also rare in the literature. We aimed to study the number of adult mosquitoes and the taxonomic composition of the trapped material in a detached house area in the Balaton Riviera. It was proposed that the phenology of mosquitoes is in correlation with the actual meteorological conditions such as daily temperature, precipitation and air pressure.

Materials and methods

Study site

Mosquito trapping and meteorological measurements were performed in Felsőörs, Veszprém County, Hungary in a private garden of a detached house at 233 m above sea level. The trapping site is located 4.5 km north of the coast of Lake Balaton, the largest lake in Central Europe, and 8.5 km southeast of the centre of Veszprém in the Balaton Highland. The distance of the closest forest from the trapping site is 170 m. There are no notable (larger) mosquito breeding habitats such as swamps, lakes, or marshes within the 400 m radius of the site. The prevailing wind has a northwest to southeast direction. The chemical mosquito control of the coastline of Lake Balaton does not affect the study site due to the distance of the lake (Fig. 1).

Mosquito trapping

The mosquito trapping was performed in the second part of the year to avoid the main season of univoltine mosquitoes (mainly of certain *Ochlerotatus* species) which have a relatively short unimodal activity in early summer in Hungary. A Bio Mosquito Trap^{TM} device (Fig.2 left) was operated at one trapping site in Felsőörs during 90 consecutive nights between the 3rd of July and the 8th of October 2016. Although 90 days at first glance may seem to be a relatively short period, in the literature, there are examples of successful 30-day-long mosquito screenings (e.g., Zittra *et al.* 2015). Andreadis *et al.* (2001) performed similar mosquito surveillance from June through October for the surveillance of the West Nile virus in Connecticut. Bio Mosquito Trap is a photocatalytic trap for capturing mosquitoes in an indoor-outdoor environment. The used trap is particularly suitable for use in sheltered outdoor areas (terraces, gazebos) or indoors. The technical properties of the

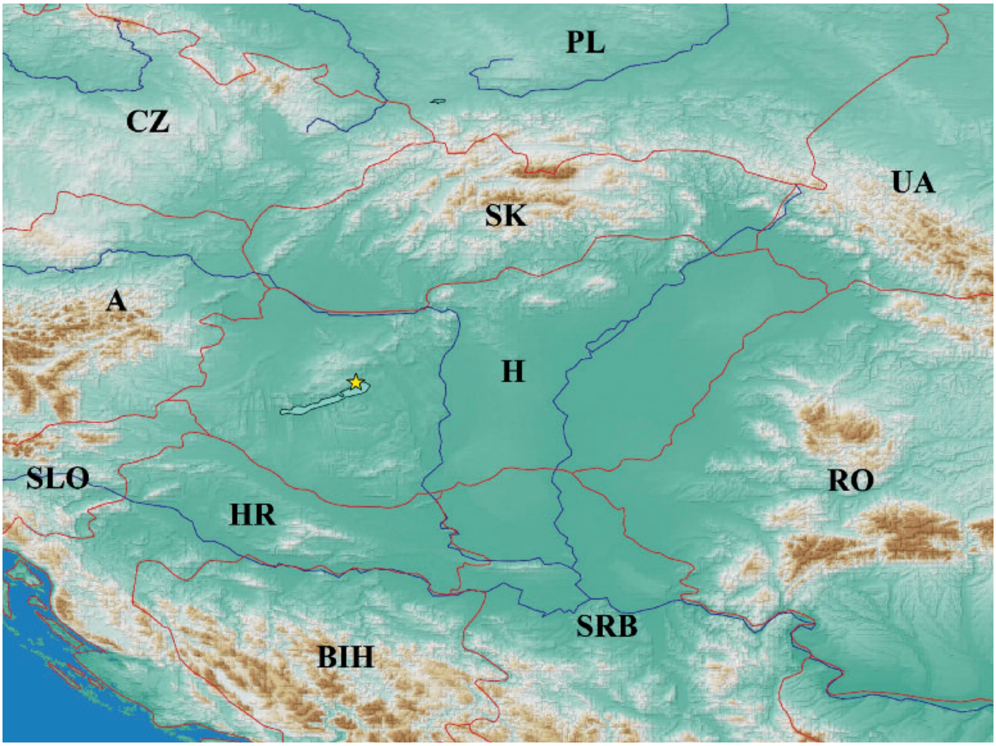

Fig. 1. The localization of the study site in Hungary marked with a yellow star (A: Austria, BIH: Bosnia and Herzegovina, CZ: the Czech Republic, H: Hungary, PL: Poland, RO: Romania, SK: Slovakia, SLO: Slovenia, SRB: Serbia, UA: Ukraine).

trap are the following: power: 220 V-50 HZ, power consumption: 26 W, weight: 1.7 kg, range: 5 m, regional coverage: 80 m^2. This ultraviolet-A radiating mosquito trap is treated with titanium oxide which with health releases CO_2. The main attractants for mosquitoes are heat, light, and CO_2. In two cases, due to technical problems, the trappings were unsuccessful. The trap was operated from 8.00 PM to 8.00 AM. The mosquito trapping was performed in an open garage and was protected from heavy rains and strong wind gusts.

Measuring of meteorological conditions

The following meteorological factors were measured in the study: daily mean, minimum and maximum temperature, the daily sum of precipitation and air pressure. We omitted relative and absolute humidity and wind values because we aimed to monitor the factors which are widely measured and are relatively independent of the vegetation and building density. Air humidity very strongly depends on the type of ground and the evapotranspiration of the environment. For example, the time of increased air humidity due to rain is much shorter in an urbanized area where the rainwater is drained compared to a forest area. The large and medium-scale topography and landmarks including the wind shading buildings and facades can create hectically variable wind conditions which also depend on the wind direction.

A Velleman WS1080^{TM} wireless weather station (dcf clock outdoor sensor) was used (Fig. 2 right) to detect the alterations in meteorological conditions. The station has indoor and outdoor units. The station measures the indoor and outdoor temperature, indoor and outdoor relative humidity, air pressure reading (absolute or relative), rainfall, wind speed, windchill and dew point temperature.

Synoptic data

The daily synoptic maps of Europe were gained from the archive of the Hungarian Meteorological Service (OMSZ 2005-2018). The UTC 00:00 (2.00 A.M.) and UTC 02:00 (4.00 A.M.) synoptic maps were available. The actual synoptic situations of the studied site were characterized by front position categories: post-cold front situation, the south edge of an arriving cold front, post-cold front situation forming anticyclone, anticyclone, pre-front saddle situation, slowed down frontal zone, frontless situation etc.

Fig. 2. Operating Bio Mosquito Trap (left) and the Velleman WS1080^{TM} meteorological station (right).

Software and statistics

Daily mean, maximum, minimum temperatures, precipitation sum, air pressure and the number of cached mosquitoes were used in the daily timescale in the analyses. In our previous trapping activities, we observed that mosquitoes are active mainly in the evening hours. Due to this fact, the meteorological data of the same day were used when the trapping activity started. Linear regressions were performed by 'Correlation and Regression' and 'Basic Multiple Regression' tools of the free statistical software Vassarstats (Lowry 2004). The Chi-Square Test and Fisher Exact Probability Test were performed by the freely accessible Wessa statistical program (Wessa 2012).

The linear and multiple regression analyses were also performed by using positive and negative lags because theoretically it can be hypothesized that

1) the biological effects of abiotic factors appear immediately or some days after the event (classical causal approach), directly affecting the activity or influence the ontogeny of animals or
2) mosquito activity depends on meteorological factors like air pressure, temperature, wind, and air humidity. These factors generally exhibit characteristic changes before, during and after the different weather fronts. Under and just before their arrival, cold fronts in summer can notably alter the convective environment by, e.g., the increase of convective available energy and the decrease of convective inhibition resulting in changing wind shear, the forming of clouds and the consequent decrease of insolation and the drop of temperature (Kunz et al. 2020).

Results

Collected species

A total of 1716 mosquitoes was trapped from 3 July 2016 to 8 October 2016 and 19 mosquito species were found. According to the genera 2 *Aedes,* 3 *Anopheles,* 1 *Coquillettidia,* 3 *Culex,* 1 *Culiseta,* 8 *Ochlerotatus* and 1 *Uranotaenia* species were found. The identified mosquito species can be seen in Table 1.

Cx. pipiens pipiens formed the majority (69.29%) of mosquitoes with 1189 individuals. *Ae. vexans* was the second most frequent species with 211 individuals forming 12.30% of collected mosquitoes. *Oc. sticticus* and *An. maculipennis* were the third and fourth most frequent species with 79 and 49 collected imagoes forming 4.60 and 2.86 % of the material. For further total number and frequency data, see Table 1.

The number of mosquitoes showed a decreasing trend in the studied 90 days-long period. The daily mean number of caught mosquitoes was 3 individuals per day during the total trapping period showing decreasing tendency over time (July: 4.37 August: 3.13 September: 2.93 and October: 1.67; Fig. 3A). The number of daily trapped mosquitoes showed notable variance. Since *Cx. pipiens pipiens* formed 69.29% of the collected material, the daily number of this species determined primarily the run of the curve of mosquito activity (Fig. 3B).

Table 1. The number and percentage value of trapped mosquitoes by species.

Species	Abbr.	Number of individuals	Percentage of total (%)
Aedes cinereus Meigen (1818)	Ae cin	40	2.33
Aedes vexans Meigen (1830)	Ae vex	211	12.30
Anopheles claviger Meigen (1804)	An cla	3	0.17
Anopheles hyrcanus Pallas (1771)	An hyr	1	0.06
Anopheles maculipennis Meigen (1818)	An mac	49	2.86
Coquillettidia richiardii Ficalbi (1889)	Co ric	6	0.35
Culex hortensis Ficalbi (1890)	Cx hor	1	0.06
Culex pipiens pipiens L. (1758)	Cx pip	1189	69.29
Culex torrentium Martini (1924)	Cx tor	14	0.82
Culiseta annulata Schrank (1776)	Cu ann	19	1.11
Ochlerotatus annulipes Meigen (1830)	Oc ann	12	0.70
Ochlerotatus cantans Meigen (1818)	Oc can	8	0.47
Ochlerotatus caspius (Pallas 1771)	Oc cas	13	0.76
Ochlerotatus cataphylla Dyar (1916)	Oc cat	2	0.12
Ochlerotatus excrutians Walker (1856)	Oc exc	1	0.06
Ochlerotatus flavescens Müller (1764)	Oc fla	15	0.87
Ochlerotatus geniculatus Olivier (1791)	Oc gen	9	0.52
Ochlerotatus sticticus Meigen (1838)	Oc sti	79	4.60
Uranotaenia unguiculata Edwards (1913)	Ur ung	2	0.12
Indet.	Indet	42	2.45
Sum.		1716	100

The effect of meteorological conditions on mosquito number

The linear regression coefficients of 3-days mean temperatures and 3-days trapped mosquito numbers were calculated according to zero, 1- and 2-days lags. The best correlation coefficient was found in the case of a 1-day lag. The correlation coefficient in the case of zero and 2-days lag was 0.4917 and 0.446. Significant positive linear regression ($p<0.001$, $r^2=0.5672$) was found between the mean air temperature of consecutive 3 days and the number of trapped mosquitoes using a 1-day lag. The x-intercepts are 11°C (0-day lag), 11°C (1-day lag) and 9°C (2-days lag).

Based on the results of multiple regression analyses, temperature values (daily mean minimum and maximum) have a moderately strong positive effect on the daily trapped mosquito numbers. The sums of daily precipitation and mosquito numbers show a very weak positive correlation, while between the daily air pressure values and the trapped mosquito numbers a weak negative correlation was found. In the case of the most abundant four mosquito species, similar correlations were observed, although weak and very weak correlations were found between precipitation and the

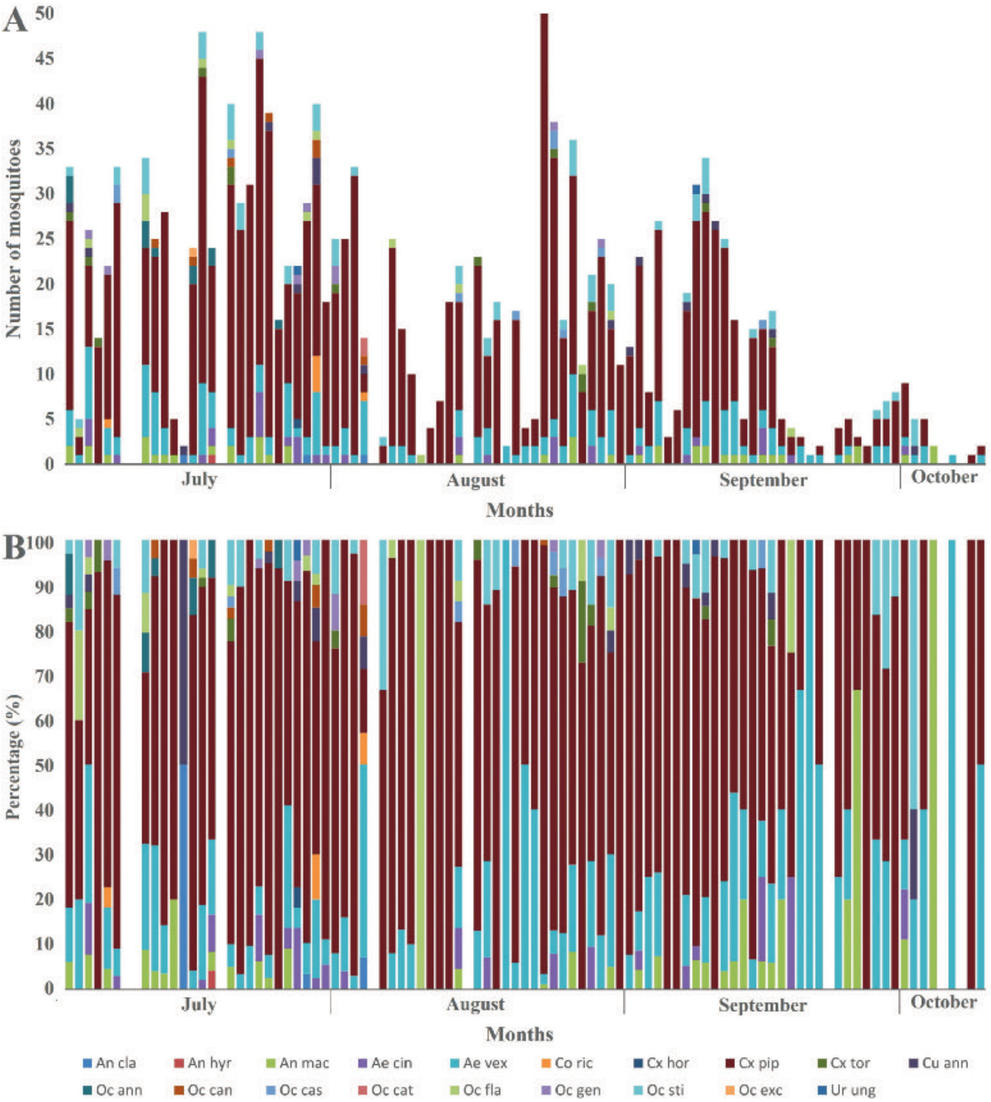

Fig. 3. The number and taxonomical composition of caught mosquitoes (A: absolute numbers, B: percentages according to the daily total number; for the abbreviated names of species, see Table 1).

daily trapped number of *Ae. cinereus* and *Cx. pipiens* mosquitoes, in contrast to the very weak correlation which was found in the case of the daily total mosquito numbers. The starting-point constants were as follows: -537.3828 (mosquitoes, **Mosq**), -416.0822 (*Cx. pipiens*, **Cx. pip**), -4.5123 (*Ae. cinereus*, **Ae. cin**), 19.7215 (*Ae. vexans*, **Ae vex**), -3.4024 (*An. maculipennis*, **An. mac**) (Table 2).

Table 2. Correlation matrix of the multiple regression analyses using 0 day-lag.

	Tmean	Tmax	Tmin	Prec	Press	Mosq	Cx pip	Ae cin	Ae vex	An mac
Tmean	1	0.956	0.914	0.144	-0.353	0.594	0.441	0.281	0.412	0.25
Tmax	-	1	0.759	0.029	-0.222	0.543	0.395	0.257	0.421	0.279
Tmin	-	-	1	0.308	-0.499	0.576	0.412	0.298	0.377	0.247
Prec	-	-	-	1	-0.384	0.069	-0.051	-0.12	0.088	0.05
Press	-	-	-	-	1	-0.171	-0.003	-0.063	-0.159	-0.097
Msq	-	-	-	-	-	1	1	1	1	1

The multiple regression analyses of the data of the collected daily mosquito number were repeated using 1, 2, 3, -1-day lags. The results showed that the adjusted regression coefficient, and the ratio of the expected variance and unexpected variances (*F* statistic values in the ANOVA table) were the highest in the case of using 1-day lag (Tables 3-4).

Table 3. The starting-point constants (a) and the standardized regression weights (b) of multiple regression analyses of five meteorological factors and the daily number of trapped mosquitoes using -1 to 3 days-lags. T_{mean}: mean daily atmospheric temperature; T_{min}: minimum daily atmospheric temperature; T_{max}: maximum daily atmospheric temperature; Prec: daily precipitation; Press: daily mean air pressure.

Lags (day)	a	r^2/B	T_{mean}	T_{max}	T_{min}	Prec	Press	Multiple R^2	Adjusted Multiple R^2
-1	-181.3392	r^2	0.532	0.473	0.548	0.173	-0.244	0.3125	0.2747
		b	-3.0887	1.998	3.158	0.2454	0.1619		
0	-392.3114	r^2	0.594	0.543	0.576	0.069	-0.171	0.3693	0.3347
		b	1.5083	-0.1931	1.2336	-0.1629	0.3624		
1	-537.3828	r^2	0.567	0.54	0.491	-0.057	-0.036	0.4093	0.3768
		b	22.5567	-10.6204	-9.323	-0.1576	0.5039		
2	-1235.1766	r^2	0.401	0.312	0.433	0.051	0.023	0.3297	0.2929
		b	21.3033	-11.2966	-7.1526	0.1087	1.1995		
3	-1219.0798	r^2	0.345	0.242	0.419	0.203	-0.04	0.262	0.2214
		b	8.9223	-5.0032	-1.3705	0.5455	1.1849		

Table 4. The detailed ANOVA table of the multiple regression results.

Lags(day)	**p**	***F***	**SS**		**df**	**MS**
-1	<.0001	4.33	Regression	6801.3729	5	1360.2746
			Residual	14965.5137	91	164.4562
			Total	21766.8866	96	
0	<.0001	10.66	Regression	8039.2129	5	1607.8426
			Residual	13727.6737	91	150.8536
			Total	21766.8866	96	
1	<.0001	12.61	Regression	8908.9705	5	1781.7941
			Residual	12857.9161	91	141.2958
			Total	21766.8866	96	
2	<.0001	8.95	Regression	7176.4326	5	1435.2865
			Residual	14590.454	91	160.3347
			Total	21766.8866	96	
3	<.0001	6.46	Regression	5702.6606	5	1140.5321
			Residual	16064.226	91	176.53
			Total	21766.8866	96	

The effect of synoptic situations on mosquito number

Mosquito number was thought to be high or low if the daily mosquito number was 10 individuals – higher or lower than the 90-days long-trend predicted daily value. According to this criterion, the daily mosquito numbers were high in 18 21 23-25, and 30 July, on 23-24 August, and on 24 8-11 September. The mosquito numbers were low in 7-8 15-16 July, 5-6 9-12 19, and 21-22 August 2016. Among the above-average mosquito number-related synoptic situations (hence it is abbreviated as '*above average synoptic situations*'), the following ones occurred: anticyclone saddle situation (Fig.4A), tangential cold front (Fig.4B), the centre of a shallow cyclone (Fig.4C), occlusion (double front) effect (Fig.4D), arriving cold front (Fig.4E), post-cold front situation (Fig.4F and H), the south edge of an arriving cold front (Fig.4G), forming anticyclone (Fig.4I), anticyclone (Fig.4J), pre-front saddle situation (Fig.4K), slowed down frontal zone (Fig.4L). Among the below the average mosquito number-related synoptic situations (hence: '*below average synoptic situations*'), the following ones occurred: the east rim of an anticyclone (Fig.4M) and the east edge of an anticyclone (Fig.4U), characterless situation (Fig.4N and P), the southern rim of a cold drop (Fig.4O), the edge of an anticyclone (Fig.4Q), warm front effect in the reversing branch of an anticyclone (Fig.4R), the south edge of an anticyclone (Fig.4S and T), arriving cold front (Fig.4V), characterless situation (Fig.4W and X).

It was observed that the below-average catches occurred mainly during or 1-2 days after the front passages, the above-average catches occurred during front-free periods in general during high atmospheric pressure situations. Based on the Chi-

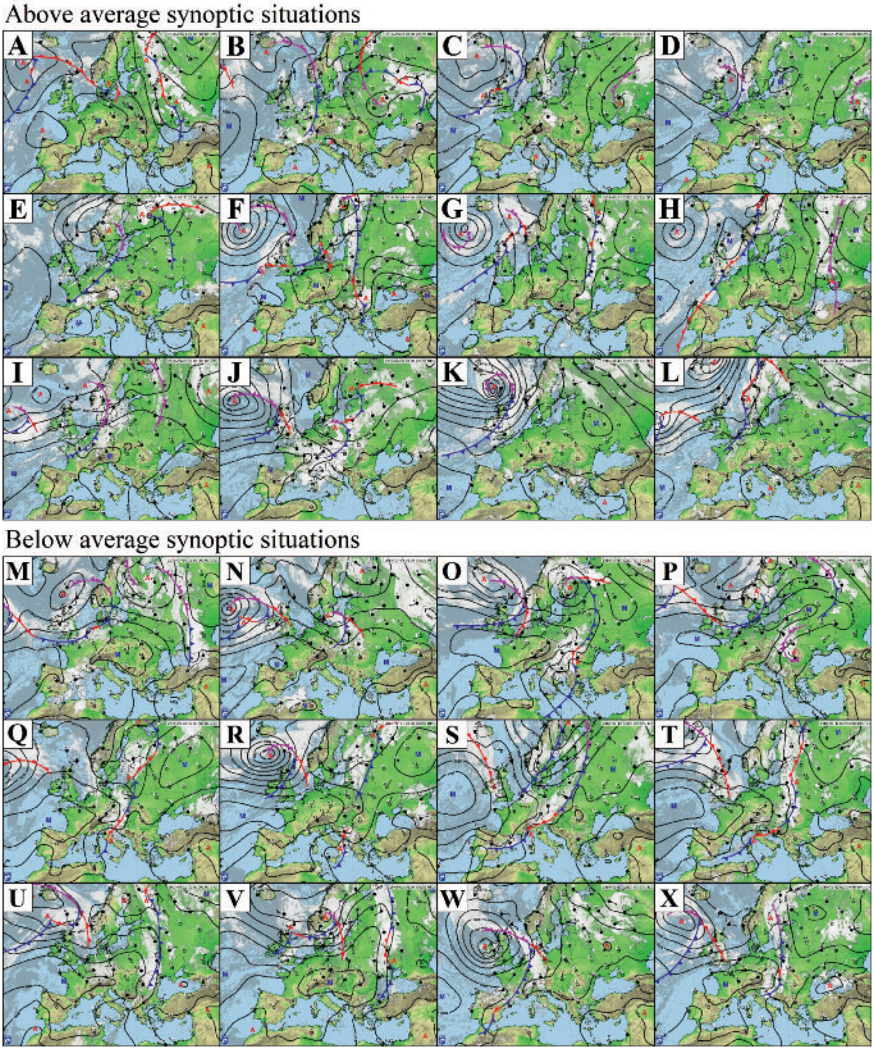

Fig. 4. Above average synoptic situations: UTC 00:00 July 19 (A), UTC 02:00 July 22 (B), UTC 02:00 July 24 (C), UTC 00:00 July 25 (D), UTC 00:00 July 31 (E), UTC 02:00 23 August 2016 (A), UTC 02:00 24 August 2016 (B), UTC 00:00 August 25 (C), UTC 02:00 September 3 (F), UTC 00:00 September 5 (G), UTC 02:00 September 10 (H), UTC 00:00 September 11 (I); below average synoptic situations: 00:00 UTC 8 July 2016 (M), 02:00 UTC 9 July 2016 (N), 02:00 UTC 16 July 2016 (O), 02:00 UTC 17 July 2016 (P), 02:00 UTC 6 August 2016 (Q), 00:00 UTC 7 August 2016 (R), 00:00 10 August 2016 (S), 02:00 11 August 2016 (T), 00:00 UTC 12 August 2016 (U), 00:00 UTC 13 August (V), 00:00 UTC 20 August (W), and 02:00 UTC 22 August 2016 (X). A’: low ‘M’: high atmospheric pressure (OMSZ (2005-2018)).

Square and Fisher Exact Probability tests, a strong significant correlation was found between the frontal or post-frontal synoptic situations and the below-average mosquito catches (Tables 5-6).

Table 5. The 2x2 contingency table of the data.

The 2x2 contingency table of the data.			
		Mosquito number	
		Below	*Above*
Synoptic situation	*Frontal/post-frontal*	9	2
	Not frontal	3	11
Expected cell frequencies per null hypothesis.			
		Mosquito number	
		Below	*Above*
Synoptic situation	*Frontal/post-frontal*	5.28	5.72
	Not frontal	6.72	7.28

Table 6. The results of Chi-Square and Fisher Exact Probability tests.

Chi-square table.			
Phi		**Yates**	**Pearson**
-0.6		6.74	9
		0.0094	*0.0027*
Fisher exact probability test			
P	**one-tailed**	0.0040	
	two-tailed	*0.0048*	

Discussion

We performed a 90-days-long continuous mosquito trapping to study the effect of daily changing meteorological conditions on daily catches of adult mosquitoes in a detached house area. The previous mosquito surveys in Hungary studied the mosquito seasonality, but continuous daily catches were not performed (Mihályi and Gulyás 1963; Tóth and Kenyeres 2012; Tóth 2004, 2006). The number of mosquitoes showed a clear decreasing trend from 3rd July to 8th October. The number of trapped mosquitoes, considering the consecutive days, showed relatively high fluctuations. Tóth (2006) previously showed that the phenology of the most frequent multivoltine mosquito species shows very similar decreasing abundance patterns from middle summer to the end of autumn in Hungary (Tóth 2004). It was found that mean daily temperature is a strong significant factor, which affects the daily trapped mosquito number. The found 1-day lag suggests that the effect of the changing temperature patterns has a short latency on the daily level of mosquito activity. Our results are in accordance with the conclusions of Guoliang (2000) Qin *et al.* (2003) and Zhou *et al.* (2010) who found that temperature strongly influences the mosquito abundance, although these authors did not study the effects of short-changes of meteorological conditions. The correlation between the differences from the trends of mean daily temperature and the trapped mosquito numbers also proved that the sudden changes of temperature conditions have a notable effect on daily mosquito abundance/activity patterns. It should be noted that ambient temperature may also influence post–oviposition feeding of females (Gillies and DeMeillon 1968; Charlwood *et al.* 2011), although the degree of the effect can vary by species.

We found no significant correlation between the sum of the days with precipitation and the daily numbers of mosquitoes like Zhou *et al.* (2010). In contrast, Guoliang (2000) found a significant correlation between rainfall and the density of mosquitoes although they concluded that this effect was weak. A similar study was presented by Szepesszentgyörgyi and Rentsendorj (2006) who studied the seasonal changes of mosquito fauna in Szeged in 1999, although the statistical evaluation of the changes of meteorological conditions on mosquito activity was not performed. It is plausible that the annual precipitation patterns have the most notable influence on the seasonal (Wegbreit and Reisen 2000) or monthly mosquito abundance (Chuang *et al.* 2011; DeGaetano 2004) than the daily number of trapped mosquitoes. The passage of anticyclones with a subsequent heavy rainstorm could have a strong effect on the populations of mosquitoes (Charlwood *et al.* 2012; Koenraadt *et al.* 2004; Paaijmans *et al.* 2007). However, it is very plausible that rainfall affects the mosquito species differently. For example, in Ghana *Anopheles gambiae* Giles (1902) entered houses more during rainy nights (Charlwood *et al.* 2011) while other mosquitoes such as *Anopheles farauti* Laveran (1902) in Papua New Guinea did not enter houses when it rained (Charlwood *et al.* 1988). The drop in the number of trapped mosquitoes was observed during and before stronger cold fronts. In some cases, this effect can depend statistically on the corresponding meteorological cold fronts since some anticyclones can cause vast cooling even in summer and notable precipitation, while weaker cold fronts only cause milder cooling and dry, sunny weather.

We found a negative correlation between the trapped mosquito number and rainfall although this relationship was very weak and not significant. The possible medium-term negative effect of rainfall on mosquito numbers can be a consequence of the nutrient diluting effect of downpours when both larvae and nutrients can be washed out of the mosquito breeding habitats (Dieng *et al.* 2010). Based on the ontogeny of mosquitoes in small waters, the most plausible explanation of the cold front-preceding swarming is that 4th instar mosquito larvae and/or pupae can accelerate their development to prevent the dilution effect of downpours during the arrival of cold fronts in summer. The flushing out effect of rain can be the most dramatic during the pupal stage and in the case of *Cx. pipiens* longer rain exposure - which is characteristic of the precipitation during cold fronts – is a more notable risk from washing out than short downpours (Koenraadt and Harrington 2008). Heavy rains also have an oviposition repellent effect (Koenraadt and Harrington 2008). On the other hand, the dilution or the oviposition repellent effect can vary by mosquito species even within the same genus. For example, the abundance of *Cx. pipiens* is more dependent on rainfall than *Cx. hortensis* because the first member of *Culex* predominantly breeds in temporary small waters, and the second one prefers the permanent waters for oviposition (Gillet and Gilot 1983). Naturally in daily time resolution, these effects could not explain the changes in mosquito abundance. In addition, in the case of the populations of the mosquito *Wyeomyia smithii* Coquillett (1901) Zani *et al.* (2005) found that transient cold stress did not result in a significant loss of fitness at the population level.

Naturally, it should also not be forgotten that weather factors act together on actual mosquito activity. The weak correlation can be explained by the fact that the effect of stronger or milder cold fronts on daily wind, temperature and precipitation conditions could be very different. Roiz *et al.* (2012) found that the abundance of *Cx. pipiens* females positively correlate with mean temperature and negatively with rainfall one to four weeks before capturing. It was observed that in temperate regions mosquito-borne disease outbreaks often occur during the junctions between warm winds and cold fronts. Sellers and Maarouf (1990) described this phenomenon on the hypothesis that mosquito vectors are carried on the southern winds and land immediately when they meet the cold fronts. The changing air pressure conditions also showed a statistically significant but very weak correlation with the daily trapped number of mosquitoes. The correlation was the strongest in the case of 1-day-lag. It is plausible that mosquitoes sense the decreasing temperature and increasing air pressure conditions which precedes the arrival of the cold front and cause the decrease of the number of caught mosquitoes. The activity of mosquitoes can reflect in the temporal incidence patterns of mosquito-borne diseases. For example, in the case of malaria, Trájer *et al.* (2016) proved that the former changes in summer precipitation patterns influenced the annual malaria case number, which was directly the consequence of the changing mosquito abundances in Hungary (Trájer *et al.* 2016b). Similarly, Sang *et al.* (2014) showed that while dengue fever cases were positively associated with mosquito density, temperature precipitation, air vapour pressure, and minimum relative humidity it was negatively associated with air pressure.

It may mean that the increased activity of mosquitoes somewhat precedes 1 day the arrival of cold fronts. It is known that atmospheric conditions could have a strong effect on insect activity (Ji–Guang *et al.* 1993) and the massive swarm migration of insects can be influenced by cold fronts. For example, large dragonflies prefer to quest for prey after the passage of cold fronts (Russell *et al.* 1998). Swarming, starting immediately before the arrival of cold fronts, could be beneficial for breeding mosquitoes. The predation of dragonflies during swarming could cause notable losses for mosquito populations. This influence is so strong that it affects the timing of swarm initiation and swarm site selection (Yuval and Bouskila 1993).

The limitations of this study should also be mentioned. Although it was not really a long-term performed study conducted over many years, the strongly significant results and their correspondence to the related literary data shows that the results are reliable. Since the range of the trap is only 80 m^2 it can be assumed that this can affect the number of the collected mosquitoes although this effect cannot be significant. Tsuda *et al.* (2008) found that the mean flying distance of the females of *Culex pipiens f. pallens* is about 280- 520 m during 1-4 days and the maximum flight distance of the species is about 1200 m. Trájer *et al.* (2016a) proved that most of the canine dirofilariosis cases, which is a typical mosquito-transmitted disease in Hungary, occurred within the 524 m circle of mosquito breeding habitats reflecting the influence of the maximum flying distance of mosquitoes on the distribution of the diseases. The distance of the nearest natural forest habitat was only 170m from the trapping site where tree holes were formed in the cavity of old Turkey oaks (*Quercus cerris* L.). Garden ponds, untreated swimming pools and rainwater collectors occur in the surrounding gardens of the study site, which may serve as the potential habitats for mosquitoes (Mokany and Shine 2003). These facts indicate that the range of the source of the trapped mosquitoes was much larger than the collector range. The statistical analysis wasn't performed for distinct species but for the total daily number of mosquitoes. *Culex pipiens pipiens,* which was found to be the most abundant species, influenced strongly the found correlations. Because univoltine mosquitoes have short unimodal activity in early summer in Hungary, our study that was performed in the second half of the year represents more the response of multivoltine mosquitoes to the changing meteorological conditions. It does not seem to be a bias of the study since the potential vectors of such mosquito-borne diseases like WNF and the most notable causes of mosquito nuisance such as *Ae. vexans* are multivoltine mosquitoes, and these mosquitoes reach their abundance maximum in August and September in Hungary (Tóth 2004). Naturally, for the large-scale monitoring of mosquito-transmitted arboviruses longer and wider trapping efforts should be required.

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