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Late flooding combined with warm autumn – potential possibility for prolongation of transmission of mosquito-borne diseases

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Abstract: Alluvial forests of southeastern Moravia and adjacent Slovakia and Austria have frequent massive mosquito outbreaks due to flooding from the Morava and Dyje rivers. Flooding occurs almost regularly in spring due to snowmelt and irregularly in summer after heavy rain. Mosquito occurrence after spring flooding is less serious and involves several species. Much greater occurrence is seen after summer flooding. Calamities in such periods are caused mainly by *Aedes sticticus* and *Ae. vexans*. Flooding at the turn of summer to autumn is rare and, when it does occur, usually is not followed by substantial increases in mosquito abundance. Mosquito numbers rapidly decline during October, with captures at the month's end only in exceptionally warm autumns. In 2014, however, summer-type weather accompanied by heavy storms continued through mid-September. Subsequent temperatures were above the monthly average, leading to an additional mosquito generation and calamity. Mosquito activity was comparable with that of summer calamities. The dominant species was *Ae. vexans*, an important vector of several diseases in the area, mainly virus Ťahyňa. It is thus apparent that late floods concurrent with exceptionally warm weather can bring a mosquito calamity under Central European conditions even in autumn.

Key words: *Aedes vexans; Aedes sticticus;* autumn floods; mosquito calamities; South Moravia

Introduction

The fauna of blood-sucking arthropods, the most abundant and prevalent of which are hematophagous dipterans, constitutes a very important component of ecosystems. Blood-sucking dipteran species pose a threat to their hosts directly both as annoying tormentors and as potential vectors of disease agents, including viruses, bacteria, parasitic protozoans, and helminths. Mosquitoes (family Culicidae) comprise one of the most important groups. In the Czech Republic, 45 mosquito species have been identified to date (Minář et al. 2004). Of these, 39 species occur in Moravia (Országh et al. 2009).

Southeastern Moravia has among the highest mosquito occurrence rates in the entire Czech Republic. The area has frequent but irregular massive occurrences of floodwater mosquito species of the genus *Aedes*. A great deal of attention has therefore been devoted to monitoring mosquito occurrence in this area (Olejníček et al. 2003; Minář et al. 2004; Rettich et al. 2007; Šebesta et al. 2010, 2012a, 2013). Frequent mosquito occurrence is also a concern in adjacent Austria and Slovakia (Seidel 2011; Strelková & Halgoš 2012). During 2007–2010, the non-indigenous mosquito species *Anopheles hyrcanus* (Pallas, 1771) was captured at Nesyt Pond (Šebesta et al. 2009) and in 2012 in Austria (Vienna) (Lebl et al. 2013). On the same sites this species became the most frequent species of the genus *Anopheles* (Šebesta & Gelbič 2015; Lebl et al. 2015). An invasive species, *Aedes albopictus* (Skuse, 1894), which is causing serious problems in some territories of southern Europe (namely in Italy) (Medlock et al. 2015), was captured in South Moravia during 2012 (Šebesta et al. 2012b). In two close sites 17 larvae of this species were found in ovitraps during July and August. The significance of this finding will need to be clarified in the years to come, as it is not yet known whether these individuals were imported by some means of transportation or if this finding constitutes onset of their regular occurrence.

Extensive studies have been devoted to mosquitoes as vectors of viruses and agents of serious infections. Several species of the genera *Aedes*, *Culex*, and *Anopheles* have been demonstrated to participate in the transmission of viral agents. In South Moravia, virus Ťahyňa, the causative agent of an influenza-like human disease, Valtice fever, has been isolated from mosquitoes (Danielová 1966) and so has the Rabensburg virus, which is closely related to West Nile virus (Hubálek et al. 1998, 2010). During 2013, West Nile virus genomic lineage 2 (Rudolf et al. 2014a) and Usutu virus

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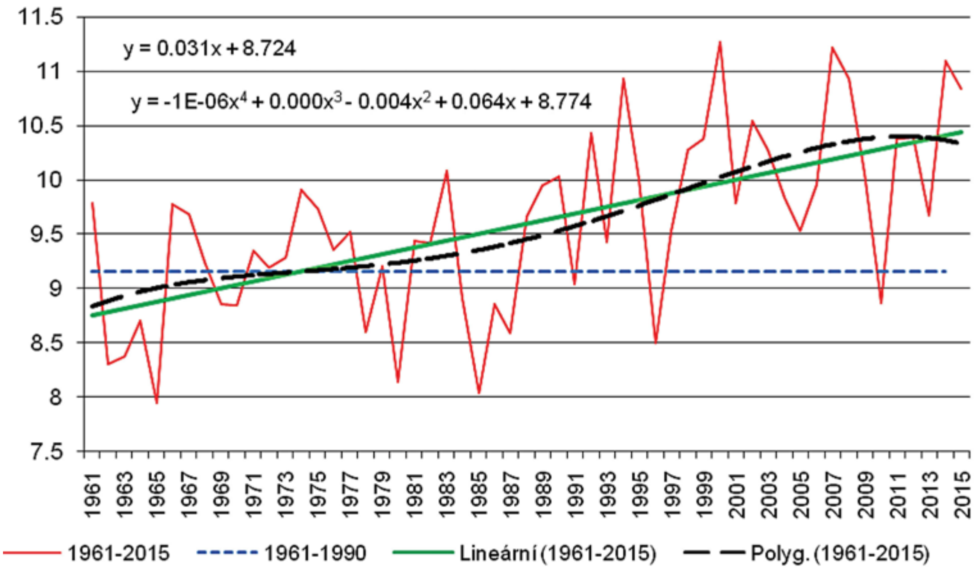

Fig. 1. Comparison of average yearly air temperature (℃) from the meteorological station at Lednice with long term average.

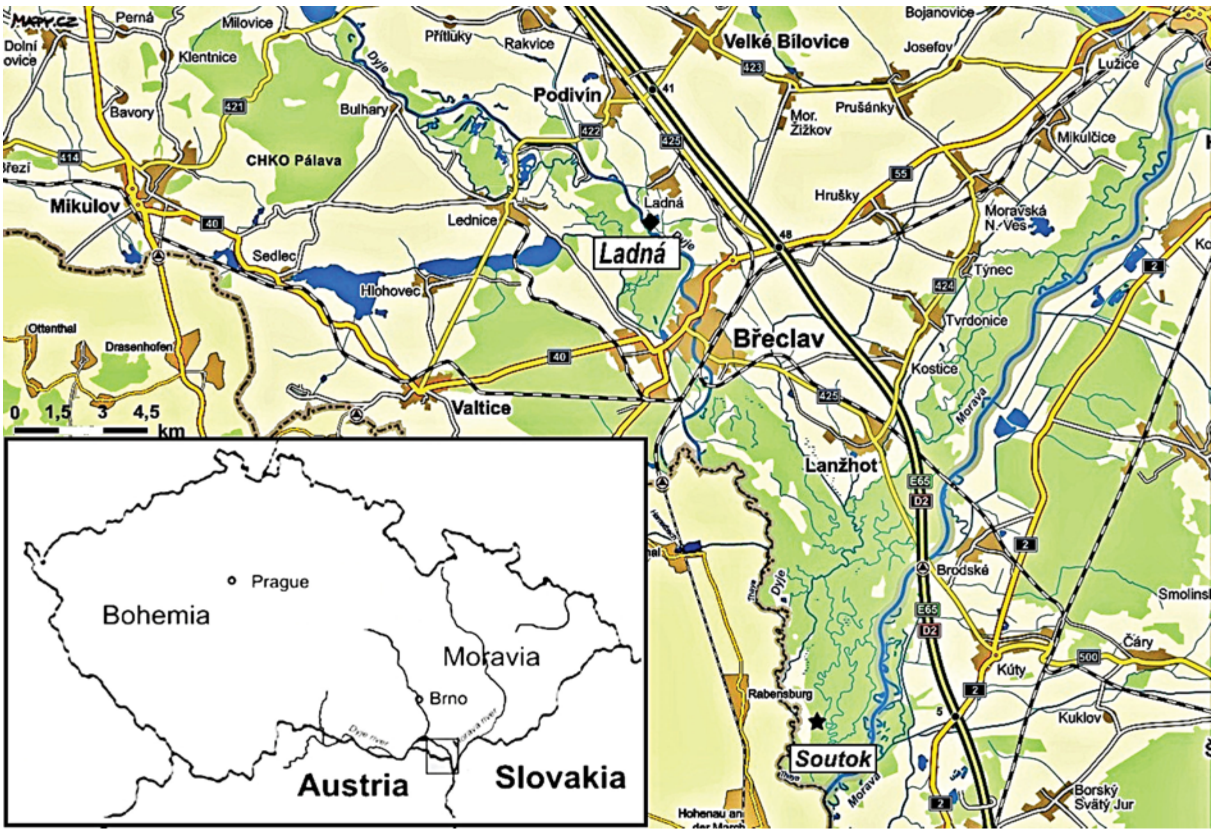

Fig. 2. Map of study sites in the Czech Republic. ★ Study Sites, ♦ measured point on the Dyje river.

(Rudolf et al. 2015) were isolated from mosquitoes in South Moravia. The nematode *Dirofilaria repens* Railliet & Henry, 1911 was isolated from the main calamitous species *Ae. vexans* (Rudolf et al. 2014b).

The present study was carried out in the course of a long term monitoring of mosquitoes in areas where their massive overabundance with negative consequence for man were frequently observed. It shows that in case of late autumn flood and extraordinary warm weather subsequent generations of mosquitoes can develop in the conditions of Central Europe. This situation could lead to a considerable increase in potential risks of pathogen transmition. *Aedes vexans* (Meigen, 1830), which plays a dominant role in late summer, is also the most important vector, not only of arboviruses (Hubálek et al. 2010) but also potentially of pathogenic filarioid helmints (Rudolf et al. 2014b) in South Moravia.

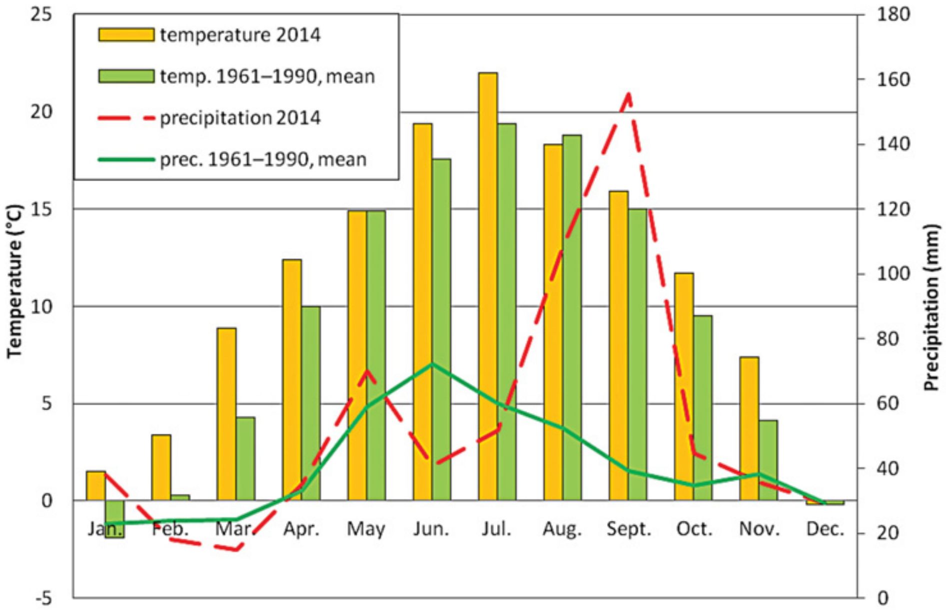

Fig. 3. Mean monthly air temperature (°C) and monthly sum of precipitation (mm) in the study area in 2014 and comparison with long-term averages (Kobylí).

Material and methods

EVS (Encephalitis Vector Survey) Mosquito Traps with dry ice (BioQuip Products, Rancho Dominiquez, CA, USA) were used to capture female mosquitoes. Traps were hung at protected locations 1 m above the ground and exposed overnight (approximately from 16:00 to 8:00 the following day). Long term monitoring in the areas around of lower Morava and Dyje river basins took place from April to October or beginning of November. These areas are characterized by frequent calamitous occurrence of mosquitoes with negative effects on the local human populations. In each site, one trap was installed for 1 day of the monitored month and year. For the purposes of this study results obtained from the trap installed at the site Soutok (48°39′ N, 16°58′ E, 147 m a.s.l.) were used. They were affected by autumn flood in the 2014 (Fig. 2). This area is located in the large bottomland forest with significant breeding grounds of flood species mosquitoes of the genus *Aedes*.

The total number of captured mosquitoes was calculated per collecting day of the month. The results obtained during 2014 were compared with data form 2013 and also with the average total number of captured mosquitoes from the monitoring period 2009–2011. These comparisons show us connections between flood, temperature and following calamity.

The captured mosquitoes were identified using the key of Becker et al. (2010). The *Culex pipiens* complex, the *An. maculipennis* complex, and *Ae. cinereus* (Meigen, 1818) – *Ae. geminus* Peus, 1970 were not distinguished within this study, as their females can be distinguished by morphological features only with difficulty.

Results and discussion

In general, locations in the temperate zone with mass occurrence of blood-sucking insects (especially mosquitoes) comprise inundated river areas, wetland and lake areas, and temporary water reservoirs. Mosquito calamities are usually caused by some species of the genus *Aedes* which lay eggs on wet ground in habitats that are flooded in the following spring or summer months.

Mosquitoes have been captured in southeastern Moravia more or less since the middle of the 20th century (Novák 1957; Hájková & Minár 1970). However, regular capture using traps has taken place only since 2008. Captured individuals have considerably varied in numbers among years as influenced by the amount of precipitation not only around the lower Morava and Dyje rivers but also throughout the catchment as well as in spring by the amount of snow and the speed at which it melts. Mosquito occurrence in this area is limited by hydrometeorological factors and related river flow rates (Figs 3, 4). Increased mosquito capture in the wild occurs usually in the investigated area from the second half of April to mid-October (Šebesta et al. 2012a, 2013). Exceptions can be seen in years during which mosquitoes may occur in the wild in small numbers also during the first 10 days of November due to late onset of winter weather. For example, on 4 November 2010, only 18 mosquitoes were captured at the study site. This situation is likely to occur more frequently as a result of climate change. The mosquitoes are represented usually by surviving individuals which had hatched at the end of summer. The dominant species is *Ae. vexans* (Šebesta et al. 2013). In addition to warm autumns, late summer flooding may also prolong the mosquito season.

During 2014, 11,393 mosquito individuals were captured by the used trap at the monitored location. Figure 5 displays the course over the year. In the consequence of very warm and dry winter, spring flood did not take place in the bottomland forest. Unusual

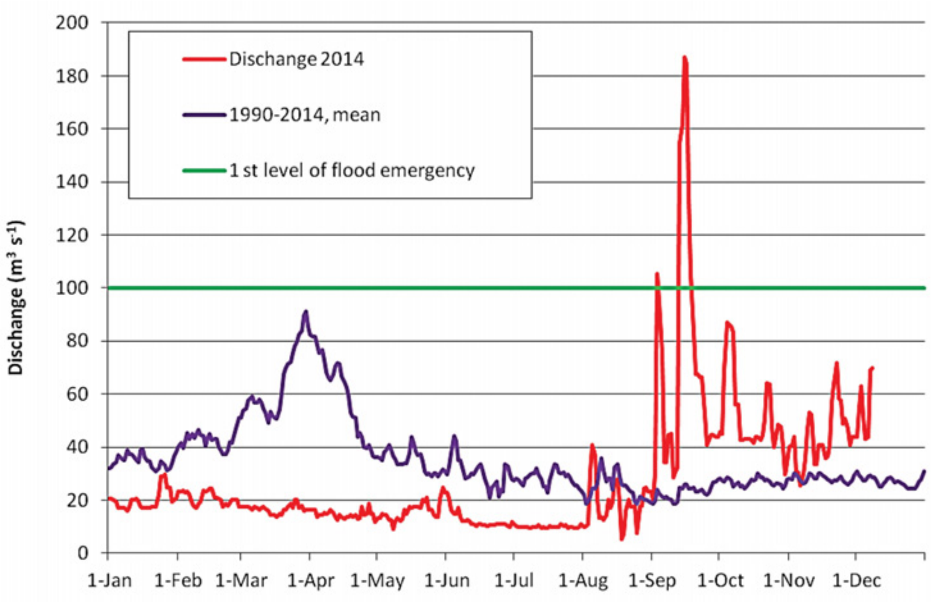

Fig. 4. Discharge in the Dyje River – Ladná ($m^3\ s^{-1}$) during 2014 and levels for declaring individual levels of flood emergency.

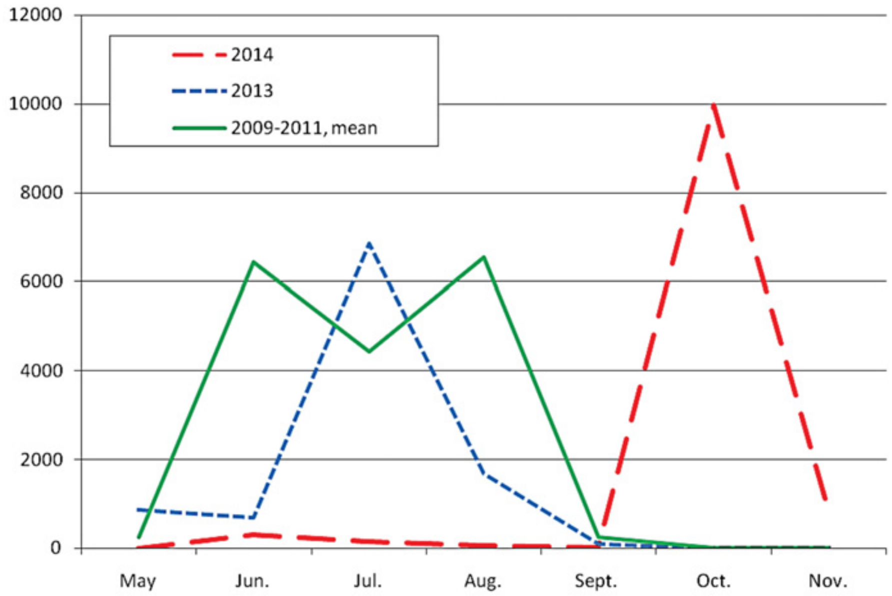

Fig. 5. Occurence of mosquitoes in the site Soutok in 2014 (No. of specimens/trap/collecting day) and comparison with the occurrence in 2013 (usual course with local summer calamity) and average for 2009–2011.

low capturing of the first mosquitoes by EVS trap was recorded till at the turn of spring and summer.

The species spectrum of these late-occurring populations comprised very few species and *Ae. vexans* clearly dominated (Table 1). *Aedes vexans* is an important vector of a number of pathogens in the area, mainly virus Ťahyňa (Danielová 1966; Hubálek et al. 2010; Rudolf et al. 2014b). Figure 5 depicts the total number of females captured in 2014 as well as a comparison with the mean from 2009–2011. This clearly shows the relationship between weather development (Fig. 3) and the number of mosquitoes occurring in the given area. A prolonged mosquito season may mean that the risk of transmitting disease agents dangerous for both humans and animals is also extended. Comparing mosquito occurrence in the spring and summer of 2014 with captures in preceding years reveals that the mosquito population was very low (Fig. 5) due to low water levels (Fig. 4). The mosquito abundance increased after flooding caused by frequent rains in August and storms with heavy rains in early September (Figs 3, 4). Abundant precipitation and a subsequent increase in river flow caused flooding of vast areas of hatching grounds, with the water remaining there for several weeks. In mid-September, mosquito occurrence at the study site was very low (33 individuals per trap per collection day, see Fig. 5, Table 1). A new generation of floodwater mosquito species hatched in masses at the end of September. Mosquito activity peaked in mid-October, with 9,970 individuals/trap/collecting day be-

Table 1. Number of captured mosquitoes by EVS trap on the site Soutok in 2014 (trap/collecting day).

	14 May	18 Jun.	16 Jul.	20 Aug.	17 Sep.	10 Oct.	6 Nov.	Total
Anopheles maculipennis s. l.		13	4					17
Aedes cinereus/geminus						5	12	17
Aedes rossicus Dolbeskin & Gorickaja, 1930							1	1
Aedes vexans(Meigen, 1830)		290	145	73	33	9950	828	11319
Aedes sticticus (Meigen, 1838)		4	3			15	10	32
Culex pipiens complex				1			3	4
Coquillettidia richiardii Ficalbi, 1899			3					3
Total number	0	307	155	74	33	9970	854	11393

ing captured. Such quantities corresponded to levels seen during summer calamities. Mosquito species composition was also similar. *Aedes vexans* was the dominant species constituting 99.8% of all individuals captured at that time. Other species were captured very rarely (Table 1). *Aedes vexans* is reported to be the dominant species also after summer flooding, although its proportion is lower (Šebesta et al. 2013). Unusually high mosquito abundance as a result of continuing warm weather was recorded even during the first 10 days of November (854 individuals/trap/collecting day). Mosquito activity ended in mid-November due to rapid cooling.

A similar extent of flooding had occurred in this area during 2010. At that time, the level 1 flood emergency measure was exceeded from 29 September to 6 October, although a new wave of floodwater mosquito species (larvae and adults) did not develop in that year. In a collection during the last 10 days of October, only 6 individuals had been captured at the study location: 5 *Cx. pipiens* complex and 1 *Ae. vexans*. Later onset of flooding might have contributed to this fact, but it was primarily influenced by the different character of weather during the two years. Whereas in 2010 temperatures were below the average in September (13.8 °C; long term average is 15.0 °C) and in October (7 °C; long term average is 9.5 °C), in 2014 temperatures were exceptionally high in September (15.9 °C), in October and during the first half of November. The second half of November was cool and, from the middle of the month, daytime maxima did not exceed 10 °C. Minima gradually dropped to 0 °C, and the very end of the month showed temperatures slightly below freezing. Another factor which could have partially affected mosquito occurrence in the autumn 2014 is the fact that in the course of this year flood did not appear and the deposited eggs did not hatch in that summer. Experience from long term observations, however, shows that outbreaks of mosquito abundances in these areas always follow flooding of breeding grounds during warm periods of the year as well as due to repeated floods.

Occurrence of non-flood species of mosquitoes (mainly of *Cx. pipiens* complex) was very low in 2014 in the consequence of dry weather in summer. Even when after autumn flood some sites were flooded, development of other mosquito species was not recorded for several weeks.

The aforementioned data demonstrate that under suitable climatic conditions (in particular delay in the onset of low autumn temperatures) a mosquito calamity in Central Europe can arise even during the autumn months (October and November). The character of such calamities (mosquito numbers and species composition) corresponds to that of summer floods (Šebesta et al. 2012a, 2013), with all the associated consequences for the local human and domesticated animal populations. The possibility of increased risk of pathogen spread should be a subject of further study. Given apparent global warming, there may be more frequent autumn mosquito calamities in the near future, and therefore it is necessary to adopt measures regulating these pest populations without disrupting life in these protected areas.

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