IDŐJÁRÁS
Quarterly Journal of the Hungarian Meteorological Service
Vol. 121, No. 3, July – September 2017, pp. 303–328

Meteorological conditions associated with West Nile fever incidences in Mediterranean and continental climates in Europe

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Abstract—West Nile fever (WNF) is the most important mosquito-borne disease in several countries of Europe. The annual phenology of the infection is mainly influenced by the seasonal activity of mosquitoes and humans. Culicid mosquitoes, the main vectors of West Nile virus prefer humid and warm conditions. This study was aimed at analyzing the West Nile fever season in Greece, Hungary, Israel and the Palestinian territories, Italy, Romania, and Serbia comparing the effect of ambient temperatures and precipitation sums on the case number of the disease. The countries were divided into two main groups – Mediterranean and continental – based on their climate. Epidemiological data of the European Centre for Disease Prevention and Control and climatic data of the European Climate Assessment and Dataset were used in the analysis. In each of the studied countries, positive correlations ($0.202 < r^2 < 0.746$; average: 0.531, SD: 0.23) were found between the monthly mean temperature and WNF case numbers. In contrast, in each of the studied countries negative correlations ($-0.131 < r^2 < -0.717$; average: –0.360; SD: 0.25) were found between the monthly precipitation sums and WNF case numbers. The mean monthly temperature in months when WNF cases were observed ranged between 15.8–28.1 °C (SD: 4.73). The case number weighted mean of the monthly temperature during the WNF-affected months varied between 17.4 to 28.8 °C (SD: 4.40). West Nile fever seasons started in June or July at 18.9–24.0 °C mean monthly temperatures (average: 21.6 °C, SD: 1.65). The WNF season ended in October or November at 18.7–5.3 °C mean monthly temperature regimes (average: 10.1 °C, SD: 5.43). The maximum lengths of the seasons were 3 to 5 months. WNF cases mainly occur in the warm or hot summer continental, the hot and dry summer Mediterranean, and the subtropical areas of Europe. The found different strength of impacts of the precipitation sums on the WNF case numbers in the Mediterranean and temperate climate countries in summer can be explained by the fact that while in humid temperate regions mosquitoes can find their breeding habitats without extreme rainfall events, in the Mediterranean countries, heavy rainfalls create suitable breeding habitat waters for mosquitoes.

Key-words: West Nile fever, temperature, precipitation, Köppen-Geiger climate classification

1. Introduction

West Nile fever (WNF) is an important mosquito-borne infection in the temperate regions of the Northern Hemisphere. The first WNF cases were detected in Europe (Albania) in 1958. Notable outbreaks were recorded already in the 1960s, the 70s and the 90s on the Old Continent (*Bardos*, 1959). Now, WNF is prevalent in the entire Mediterranean region and the continental parts of East Europe (*Hubálek* and *Halouzka*, 1996), but it is also an emerging disease in North America and North Africa. West Nile virus (WNV), the etiologic agent of WNF (*Goldblum et al.*, 1954) was first isolated in Uganda, in 1937 (*Barzon et al.*, 2015; *Kuno et al.*, 1998). The virus is the member of Flaviviridae, belonging to the Japanese encephalitis antigenic group of Flavivirus. Based on the glycoprotein envelope of the virus, two major human pathogenic lineages were distinguished: Lineage-1 and Lineage-2 strains (*Kemenesi et al.*, 2014; *Pachler et al.*, 2014; *Bakonyi et al.*, 2006). In 20–30% of the cases, WNV causes flu-like symptoms after a 2 to 14-day latency period, although about 70–80% of the cases is asymptomatic, and neurological symptoms appear in less than 1% of the cases. Individuals above the age of 65 have higher risk for morbidity and neurological manifestations (*Barzon et al.*, 2015; *Hayes et al.*, 2005). The most serious manifestation of the diseases is the rare lethal encephalomyelitis in humans. The case fatality rate is about 10% in the neurological infections (*CDC, West Nile virus, Symptoms & Treatment*). The virus is transmitted by mosquitoes from avian hosts in most of cases.

The predominant vectors of WNV are different culicid mosquitoes (*Koopmans et al.*, 2007). Occasionally, WNF can be transmitted by milk to breastfeeding babies or by organ transplantation (*Sambri et al.*, 2013; *Sampathkumar*, 2003). Imported human cases are also known from the literature (*Ivanov et al.*, 1986; *Draganescu et al.,* 1977). The most characteristic, predominant mosquito vectors of WNV are the different *Culex* species (*Hannoun et al.*, 1964; *Hubálek et al.*, 1999; *Kilpatrick et al.*, 2006; *Kostyukov et al.*, 1986; *Szentpáli-Gavallér*, 2014; *Tsai et al.*, 1998; *Work et al.*, 1955). Argasid and ixodid ticks are vectors of WNV in Moldavia and Southern Russia (*Lawrie et al.*, 2004; *L'vov et al.,* 2002). Several of the vertebrae hosts of WNV are migratory birds (*Erdélyi et al.*, 2006, 2007), but the virus was also isolated in mammals (*Molnár et al.*, 1975). Antibodies were detected from humans, wetland birds (including wetland passerines), and other wild birds (e.g., migratory birds), chickens, domestic mammals as, e.g., cattle and other domestic ruminants, dogs, horses, game animals, and wild rodents. The normal cycle of the virus requires the presence of a vertebrae host, which is mainly a bird and an ornithophilic mosquito (or sometimes a hard tick) vector. It was found that two basic, bird-to-mosquito (*Hubálek* and *Halouzka*, 1999) and an alternative, bird-to-tick transmission cycles exist in East Europe (*Butenko et al.*, 1968; *Chumakov et al.*, 1968).

Climatic factors have a major effect on the range and seasonal activity of many arthropod vectors as ticks, sandfly species, and vector mosquitoes determining the seasonality and incidence of the transmitted diseases. Mosquitoes, being poikilothermic organisms, are sensitive to the changes of temperature conditions. Rising air temperature can influence positively each elements of the WNF's vector chain including the abundance and the activity of the mosquito vectors, the viral replication rate of the virus, and the spatial range of WNF (*Reisen et al.*, 2006, *Paz et al.,* 2013, *Kinney et al.,* 2006; *Kilpatrick et al.,* 2008; *Andrade et al.*, 2011). *Reeves et al.* (1994) and *Reiter et al.* (2001) found that WNF abundance and incidence are influenced by several environmental factors as heavy rains, irrigation, floods, dry and warm weather, unusually warm weather. The occurrence and incidence of the disease are primarily the function of the vector abundance. The virus is transmittable under very different climatic conditions from the cold temperate regions to the tropics. *Reisen et al.* (2006) proved that above-average summer temperatures in the United States resulted in an increased incidence of WNF due higher transmission rate of the virus by a *Culex* species to humans. The positive effect of increasing temperature on the minimum transmission rate of WNV were showed also in a modeling study (*Ruiz et al.,* 2010). Higher ambient temperatures also shorten the generation time of blood questing female mosquitoes and accelerate the evolution of the virus (*Paz et al.,* 2013; *Kilpatrick et al.,* 2008; *Meyer et al.,* 1990; *Ruiz et al.,* 2010). Positive correlations were observed between extreme high temperatures during heat-waves and the outbreak intensities of human WNF epidemics in many cases (*Dohm et al.,* 2002; *Cornel et al.,* 1993; *Epstein,* 2001; *Pats et al.,* 2003; *Paz,* 2006). It is also known that extreme hot temperature conditions can influence negatively the survival of mosquitoes (*Reisen,* 1995) and the replication of WNV in the vector mosquito organisms (*Reisen et al.*, 2006).

The ontogeny of mosquitoes requires a certain threshold temperature. Experimental investigations reveal that there is a temperature limit of the infection of *Cx. pipiens* mosquitoes with WNV (*Dohm et al.,* 2002; *Dohm* and *Turell,* 2001): the ambient temperature limit is about 14 °C (*Cornel et al.* 1993). In a laboratory experiment, *Kilpatrick et al.* (2008) confirmed that the transmission of WNV is the exponential function of degree days. Elevated temperatures not only promote the increase of the mosquito populations (*Paz* and *Albersheim,* 2008), but shorten the full replication cycle of WNV in the infected mosquitoes (*Jia et al.,* 2007; *Kunkel et al.,* 2006) and accelerate the transmission of WNV (*Kilpatrick et al.,* 2008).

The role of precipitation in the determination of the WNF season and prevalence is more controversial (*Moudy et al.,* 2007) than that of the ambient temperature, and strongly depends on the climate of a certain region. At first inspect, it seems to be obvious that higher summer precipitation sums promote the population boom of mosquitoes providing more stable and extent aquatic habitats for the vectors. In the USA, indeed, it was found that precipitation above average can promote both the boom of mosquito populations and the above-average WNF incidences (*Soverow et al.,* 2009; *Takeda et al.,* 2003). Under tropical savannah climate, where rainy and dry seasons alternate, the rainy season provide better conditions for the population growth of mosquitoes (*Campbell et al*., 2002). In Gibraltar, which area belongs to the Mediterranean climate region, WNF case number starts to increase in late summer parallel with the increase of precipitation, (*Paz et al.,* 2013). In contrast, there are evidences that expressly heavy rainfalls also can wash out the mosquito larvae from stagnant pools, channels, or even technotelmata causing the elimination of a complete mosquito generation (*Shaman et al.,* 2002; *Koenraadt et al.,* 2008). The role of the previous year's precipitation sums on the next year's WNF case numbers is also controversial. Higher precipitation sums in the previous year can either increase or decrease the current year's WNV transmission depending on the geographical location of the certain subtropical areas (*Paz* and *Semenza,* 2013; *Uejio et al.,* 2012; *Ruiz et al.,* 2010).

The aim of this study was the investigation of the influence of climatic factors on WNF case numbers in three Mediterranean (Greece, Italy, Israel, and the Palestinian Territories) and three continental climate countries (Hungary, Serbia, and Romania).

It was hypothesized that temperature has positive effect on WNF case numbers both in the Mediterranean and the temperate climate areas since temperature has general positive effect on mosquito ontogeny and the replication and transmission rate of the virus. Since under Mediterranean climate, summer is the driest season and in general, the rainy seasons provide better conditions for the population growth of mosquitoes, it was hypothesized that there is negative correlation between precipitation sums and West Nile fever case numbers in the Mediterranean countries. In contrast, it was also hypothesized that under continental climate, this correlation can be weaker than in the Mediterranean. In the continental parts of Europe, June can be the wettest month during the year creating good breeding sites for mosquitoes.

2. Materials and methods

2.1. Data

The historical West Nile fever data were derived from the ECDC's (European Center for Disease Control and Prevention) database in monthly temporal resolution (*ECDC: West Nile fever historical data 2011-2015)*. Both probable and confirmed cases were involved into the study. Data for Greece for 2015 and for Serbia for 2010 are missing. Case numbers were not converted into incidence values due to the relatively short studied period. The monthly precipitation sums and monthly mean temperature values were gained from the KNMI Climate Explorer (*Klein Tank et al.,* 2002) of the European Climate Assessment and Dataset (*Haylock et al.*, 2008), and they were averaged according to the covering grids of the NUTS3 regions where WNF cases occurred in 2011–2015. It means that the selected grids cover only the areas where West Nile fever occurred in the given country in the period 2011–2015. *Table 1* shows the employed covering grids of the WNF case containing areas.

Table 1. Coordinates of the covering grids by countries (GR: Greece, HUN: Hungary, IT: Italy, RO: Romania, ISR: Israel and the Palestinian territories, and SRB: Serbia). Note that the selected covering grids are smaller than the total covering grids of the countries

Country	N(°)	E(°)
GR	38.00 to 41.50	20.25 to 25.50
HUN	45.75 to 48.50	16.00 to 23.00
IT	44.25 to 46.50	6.75 to 13.50
RO	43.75 to 47.25	23.00 to 29.50
ISR	29.75 to 33.25	34.25 to 35.75
SRB	42.25 to 46.00	19.25 to 22.75

2.2. Statistics and plot

Multiple linear regression method was used. Only the seasonal cases were involved into the study; the extra seasonal January, February, and December WNF cases of 2011, 2012, and 2013 in Hungary were neglected in the analysis. Case number data were involved in the study only if the monthly total or mean WNF case value was above 0. Temperature values below 0°C were not plotted in the diagrams due to the representation of the temperature and case number values on a common (second) y-axis. Although in case of two countries, the WNF case numbers of one-one year were missing from the database, the temperature and precipitation values of these years were plotted in the diagrams.

The average temperature values during the WNF seasons were calculated according to two different approaches:

1) The mean temperatures of the affected months when WNF cases occurred were averaged based on the following equation:

$$T_m = \frac{\sum_{i=1}^{n} T_{monthly\ mean,i}}{n} \tag{1}$$

where T_m is the mean temperature of the affected months, $T_{monthly\ mean,\ i}$ is the mean temperature of the ith month when WNF cases occurred, and n is the number of months when WNF cases occurred.

2) The temperature values were weighted with the number of WNF cases in each month when WNF cases occurred according to the following formula:

$$T_{mw} = \frac{\sum_{i=1}^{n}(T_{monthly\ mean,i} \times N_{WNF\ monthly,i})}{\sum_{i=1}^{n} N_{WNF\ monthly,i}}, \tag{2}$$

where T_{mw} is the weighted mean temperature of the affected months, $T_{monthly\ mean,\ i}$ is the mean temperature of the ith month and the $N_{WNF\ monthly,\ i}$ is the number of WNF cases in the ith month.

3. Results

3.1. Mediterranean countries

3.1.1. Greece

In Greece, the WNF season started in July (at 24.0 °C) and ended in October (at 14.9 °C). The highest cumulative case number was observed in August (55.52% of the total). The majority (93.1%) of the cases occurred from July to August in the period 2011–2014, when the mean temperature was 24.2 °C. In July and August, the driest months during the period of 20112014, the mean precipitation sum was 13.5 mm month^{-1}, that is 27.6% of the monthly mean precipitation sum (48.7 mm month^{-1}). In Greece, the peak of the annual case number approximately coincided with the annual temperature maximum and precipitation minimum (*Fig. 1*).

The mean monthly temperature was 21.8 °C, the mean air temperature weighted with the number of cases was 24.4 °C in the months of observations of the autochthon cases (maximum: 26.1 °C, minimum: 13.1 °C). The maximum length of the season was 3 months. The data of 2015 is missing. The maximum length of the season was 4 months (excluding the imported cases; *Fig. 2*).

Based on the multiple regression analysis, strong negative correlation exists between the mean monthly precipitation sums and the corresponding WNF case numbers. In contrast, strong positive correlation was found between the mean monthly temperatures and WNF case numbers in Greece (*Table 2*).

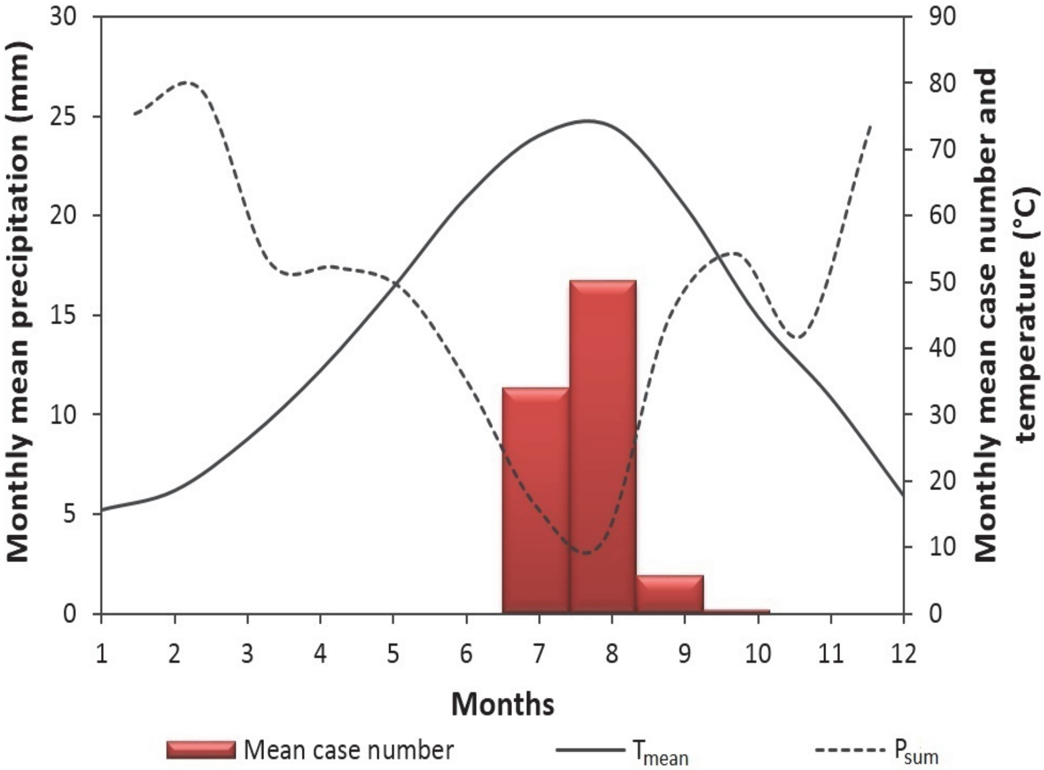

Fig.1. The mean monthly case numbers compared to the run of the mean monthly temperatures and the precipitation sums in Greece, 2011-2014.

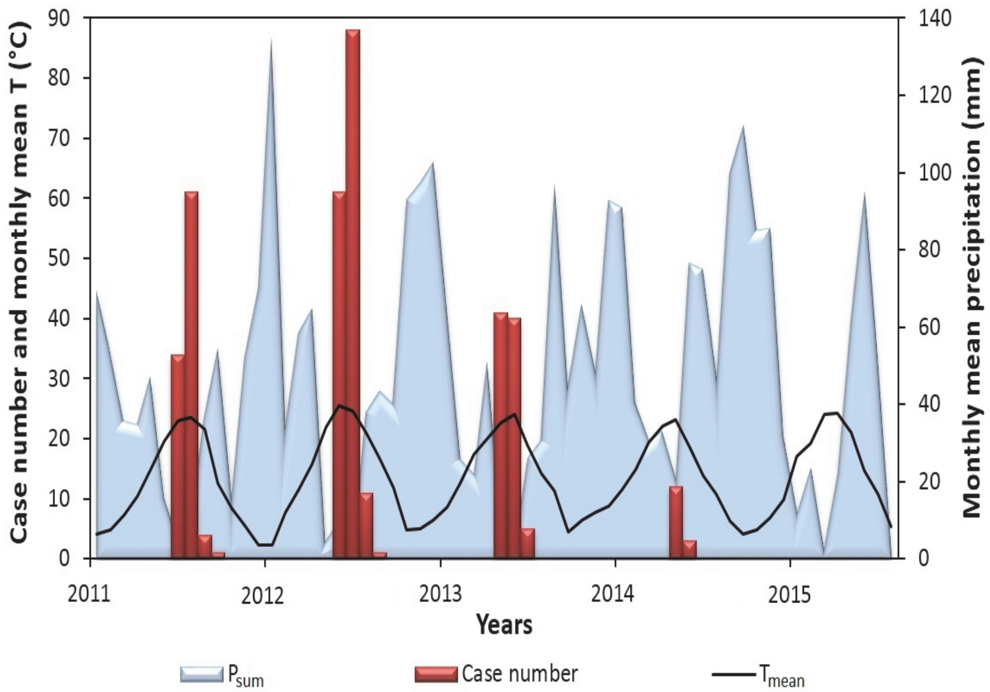

Fig.2. The number of WNF cases in 2011 to 2014 in Greece and the run of the monthly mean temperature averaged to the grid of the affected areas of the country. The WNF data of 2015 is missing from the ECDC's public historical database.

Table 2. The results of the multiple regressions in case of Greece.

Correlation matrix	T_{mean}	P_{sum}	Case number
T_{mean}	1	–0.818	0.743
P_{sum}	–	1	–0.717
Case number	–	–	1
Multiple R^2=0.5879			
Adjusted multiple R^2=0.5055			

3.1.2. Israel and the Palestinian territories

In Israel and the Palestinian territories, most of the WNF cases (the 83.74% of the total) occurred in June, July, and August (*Fig. 3*). The WNF season started before the warmest months in June (at 21.6 °C) and ended in October (at 18.75 °C). In July and August during 2011–2015, in Israel and the Palestinian territories, the mean precipitation sum was 0.2 mm month^{-1}, that is the 0.4% of the monthly mean precipitation sum (42.7 mm month^{-1}). The peak of the annual case number coincided with the annual temperature maximum and the precipitation minimum (*Fig. 3*).

The mean monthly temperature was 28.1 °C, the mean air temperature weighted with the number of cases was 28.8 °C in the months of observations of the autochthon cases (maximum: 30.4 °C, minimum: 23.1 °C). The maximum length of the season was 3 months (*Fig. 4*).

According to the multiple regression analysis, moderate strong negative correlation exists between the mean monthly precipitation sums and the corresponding WNF case numbers. In contrast, strong positive correlation was found between the mean monthly temperatures and WNF case numbers in Israel and the Palestinian territories (*Table 3*).

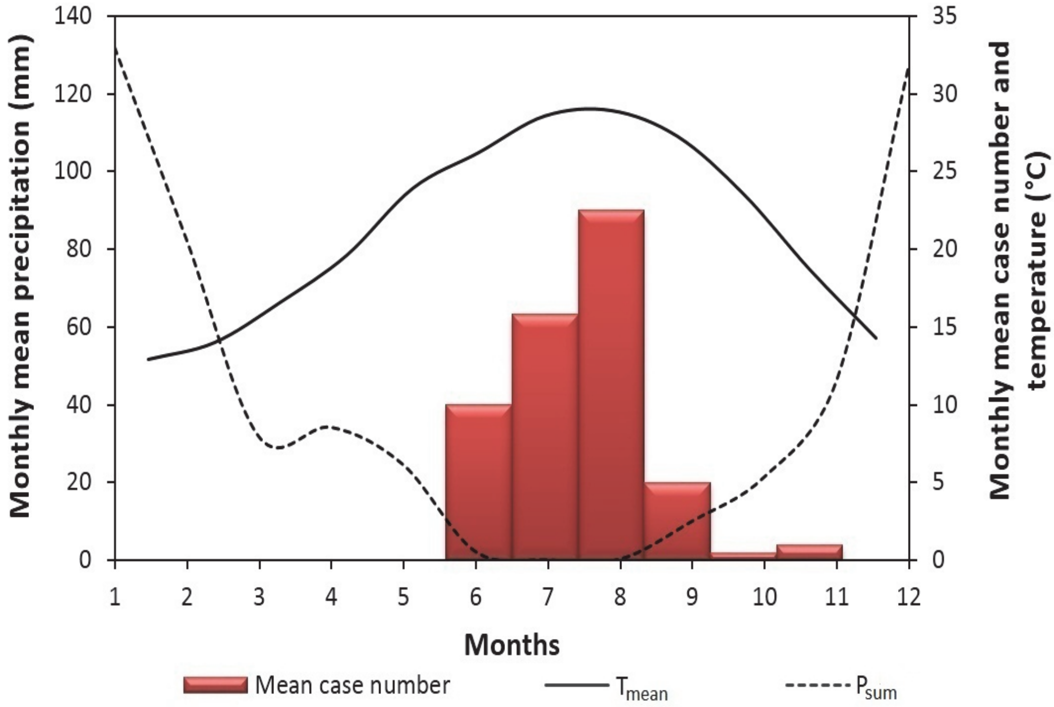

Fig.3. The mean monthly case numbers compared to the run of the mean monthly temperatures and the precipitation sums in Israel and the Palestinian territories, 2011-2015.

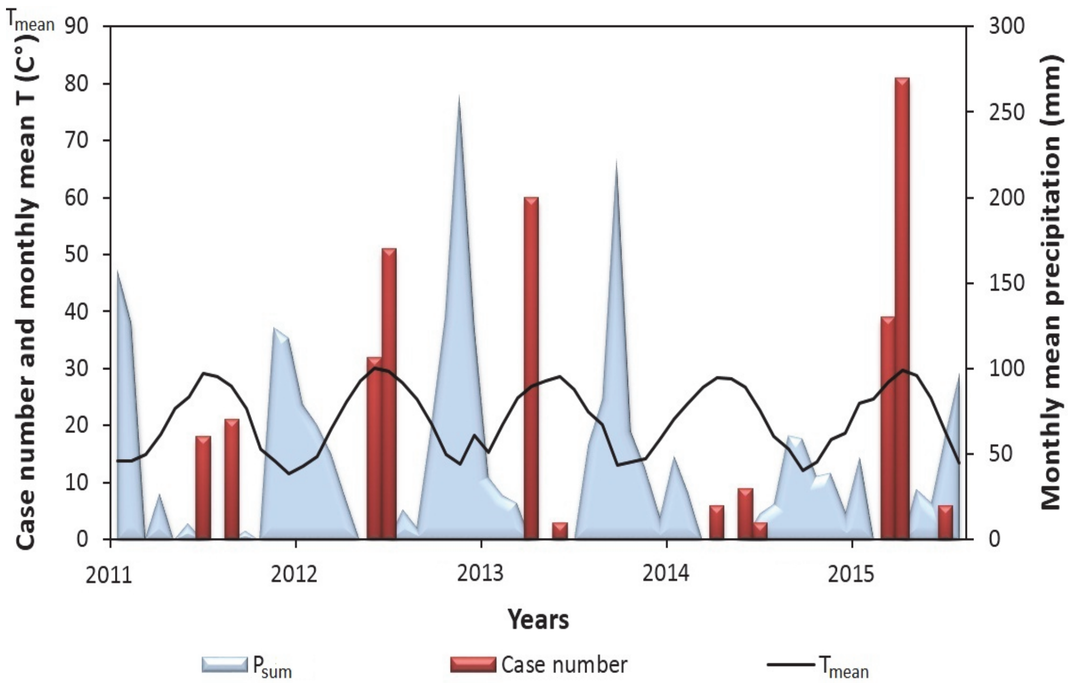

Fig.4. The number of WNF cases from 2011 to 2015 in Israel and the Palestinian territories, and the run of the monthly mean temperature averaged to the grid of the affected areas of the country.

Table 3. The results of the multiple regressions in case of Israel and the Palestinian territories

Correlation matrix	T_{mean}	P_{sum}	Case number
T_{mean}	1	–0.885	0.746
P_{sum}	–	1	–0.566
Case number	–	–	1
Multiple R^2=0.5966			
Adjusted multiple R^2=0.507			

3.1.3. Italy

In Italy, the WNF season started in August (at 22.3 °C) and ended in November (at 8.6 °C). Most of the WNF cases (89.17%) occurred in August and September. The peak of the annual case number (the 55.5% of the cases) was observed in August. The first annual cases appeared in the warmest month and showed a clear decreasing trend from July to November. In August and September during 2011–2015 in Italy, the mean precipitation sum was 76.1 mm month^{-1}, that is the 91.5% of the monthly mean precipitation sum (83.2 mm month^{-1}). In Italy, the peak of the annual case number immediately followed the annual temperature maximums and coincided with the precipitation minimum (*Fig. 5*).

The mean monthly temperature was 15.8 °C, the mean air temperature weighted with the number of cases was 18.5°C in the months of observations of the autochthon cases (maximum: 22.8 °C, minimum: 6.3 °C). The maximum length of the season was 3 months (*Fig. 6*).

According to the multiple regression analysis, moderate strong negative correlation exists between the mean monthly precipitation sums and the corresponding WNF case numbers. In contrast, strong positive correlation was found between the mean monthly temperatures and WNF case numbers in Italy (*Table 4*).

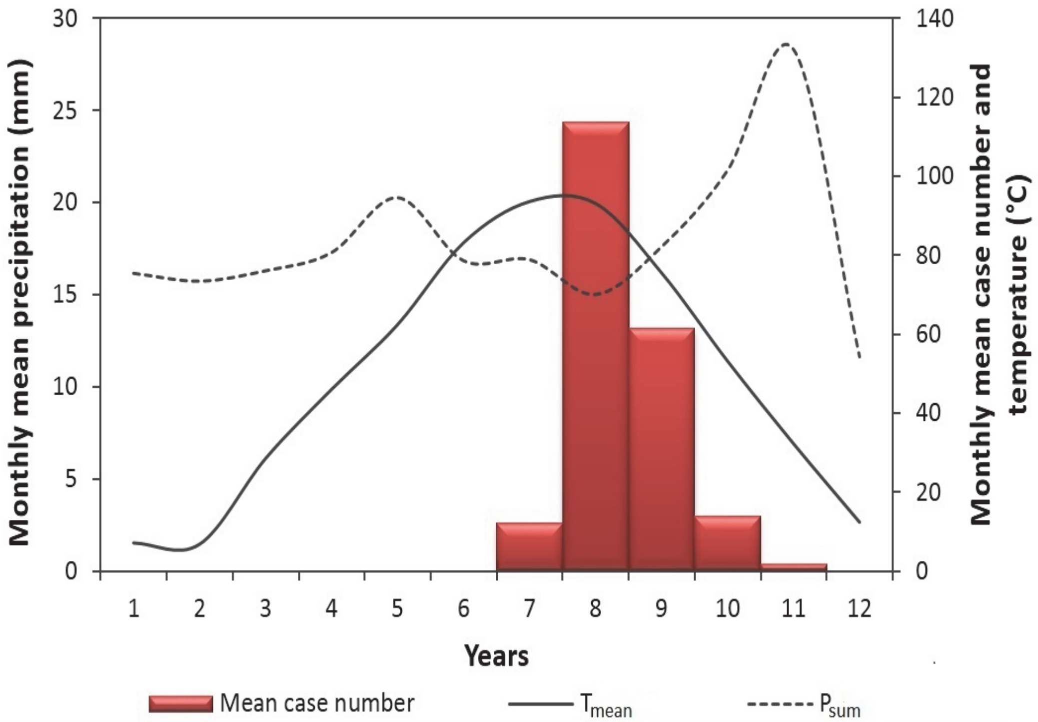

Fig. 5. The mean monthly case numbers compared to the run of the mean monthly temperatures and the precipitation sums in Italy, 2011–2015.

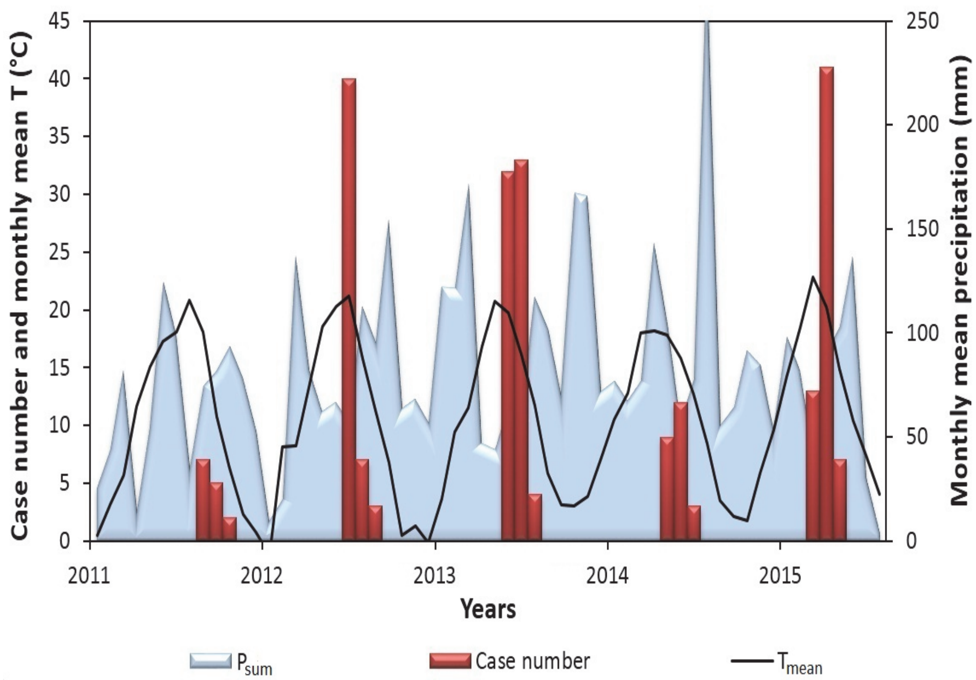

Fig. 6. The number of WNF cases from 2011 to 2015 in Italy, and the run of the monthly mean temperature averaged to the grid of the affected areas of the country.

Table 4. The results of the multiple regressions in case of Italy

Correlation matrix	**T_{mean}**	**P_{sum}**	**Case Number**
T_{mean}	1	–0.533	0.661
P_{sum}	–	1	–0.426
Case Number	–	–	1
Multiple R^2=0.44444			
adjusted multiple R^2=0.3433			

3.2. Continental countries

3.2.1. Hungary

In Hungary, the WNF season started in July (at 21.3 °C) and ended in November (at 6.1 °C) excluding the imported cases. In 2011, only one imported case was explored. From 2013, most of the cases were observed in September. In 2013 and 2014, each of the autochthon cases was recorded from August to October. The 64.5% of the total cases occurred in September. In August and September during 2011–2015 in Hungary, the mean precipitation sum was 51.6 mm month^{-1} that is the 114.9% of the monthly mean precipitation sum (44.9 mm month^{-1}). In Hungary, the peak of the annual case number followed the annual temperature maximum and the precipitation minimum (*Fig. 7*).

The mean monthly temperature was 16.7 °C, the mean air temperature weighted with the number of cases was 17.4°C in the months of observations of the autochthon cases (maximum: 23.5 °C, minimum: 7.6 °C). The maximum length of the season was 3 months (excluding the extra seasonal cases; *Fig. 8*).

According to the multiple regression analysis, very weak negative correlations exists between the mean monthly precipitation sums and the corresponding autochthonous WNF case numbers. In contrast, weak positive correlation was found between the mean monthly temperatures and WNF case numbers in Hungary (*Table 5*).

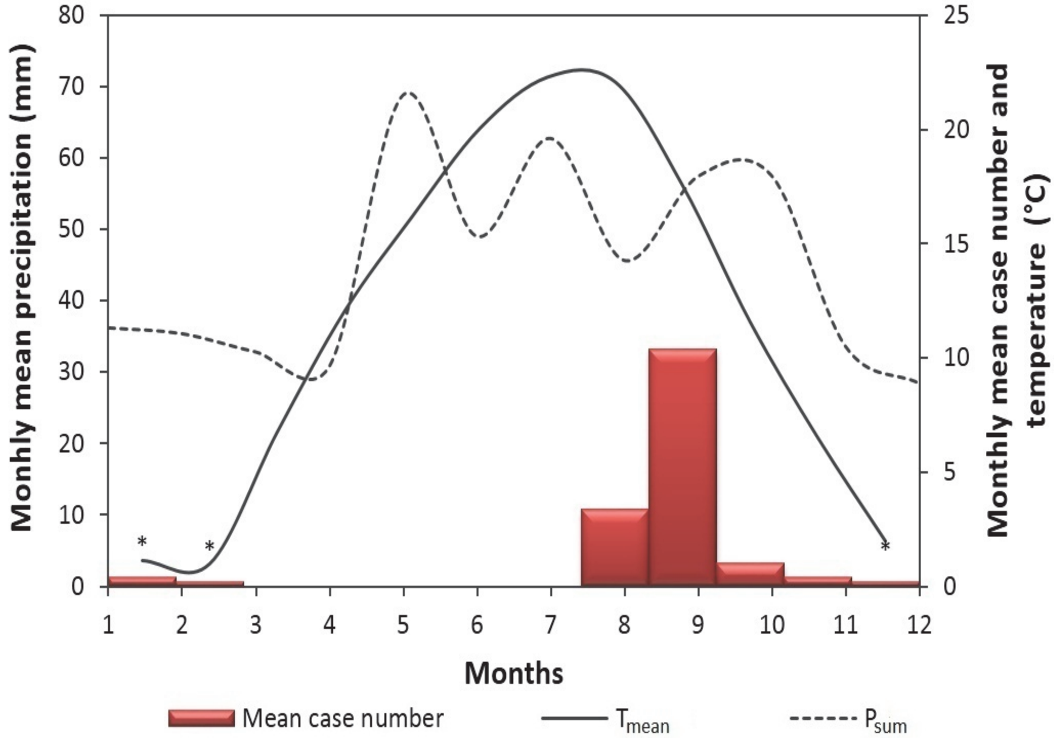

Fig. 7. The mean monthly case numbers compared to the run of the mean monthly temperatures and the precipitation sums in Hungary, 2011–2015; *: extra seasonal cases.

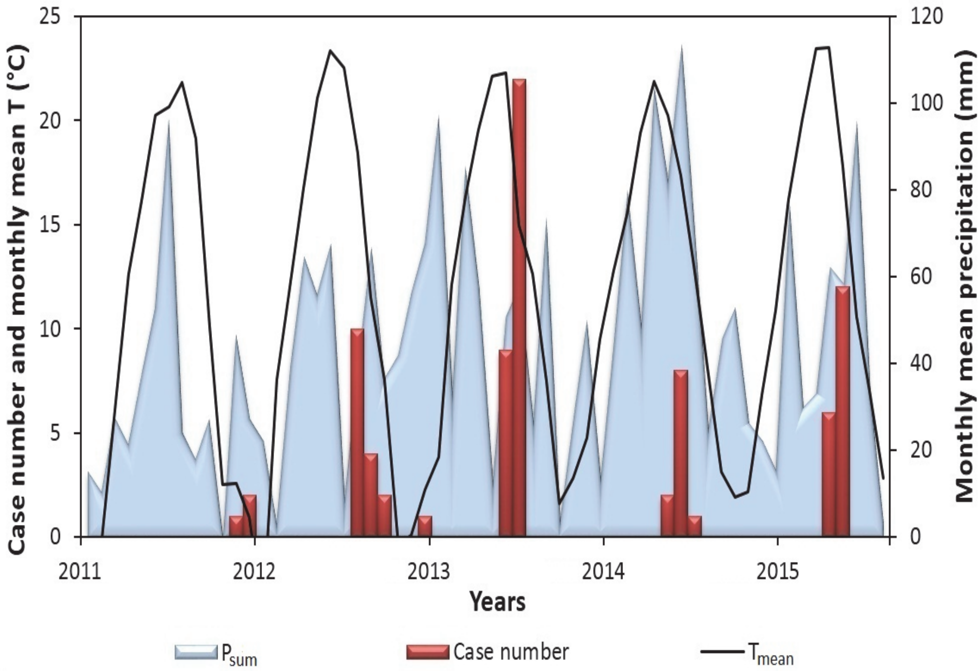

Fig. 8. The number of WNF cases from 2011 to 2015 in Hungary, and the run of the monthly mean temperature averaged to the grid of the affected areas of the country.

Table 5. The results of the multiple regressions in case of Hungary.

Correlation matrix	**T_{mean}**	**P_{sum}**	**Case Number**
T_{mean}	1	0.181	0.202
P_{sum}	–	1	–0.131
Case Number	–	–	1
Multiple R^2=0.0696			
adjusted multiple R^2=0			

3.2.2. Serbia

In Serbia, the WNF season started in June and lasted to November. Most of the WNF cases (87.8%) occurred in June, July, and August. The WNF season started before the warmest months in June (at 18.9 °C) and ended in October (at 7.0 °C). In June to August during 2012–2015 in Serbia, the mean precipitation sum was 49.1 mm month^{-1}, that is the 79.8% of the monthly mean precipitation sum (61.5 mm month^{-1}). In Serbia, the peak of the annual case number preceded the annual temperature maximum and the precipitation minimum (*Fig. 9*).

The mean monthly temperature was 17.3 °C, the mean air temperature weighted with the number of cases was 19.5 °C in the months of observations of the autochthon cases (maximum: 23.6 °C, minimum: 7.4 °C). The maximum length of the season was 5 months (*Fig. 10*).

According to the multiple regression analysis, very weak negative correlation was found between the mean monthly precipitation sums and the corresponding WNF case numbers. In contrast, weak positive correlation was found between the mean monthly temperatures and WNF case numbers in Serbia (*Table 6*).

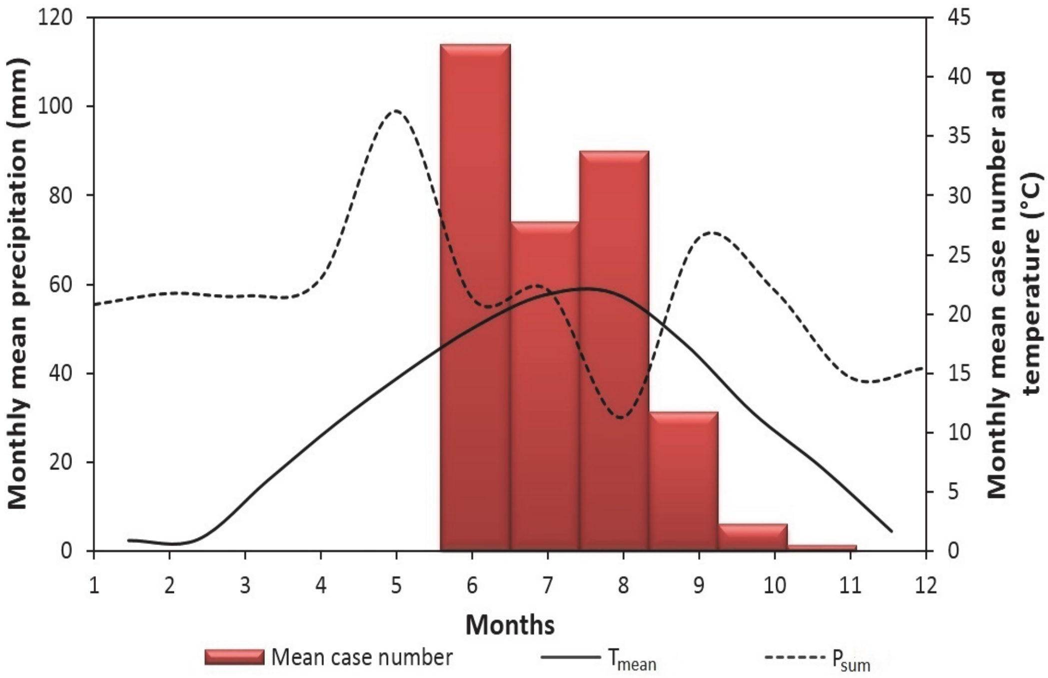

Fig. 9. The mean monthly case numbers compared to the run of the mean monthly temperatures and the precipitation sums in Serbia, 2012–2015.

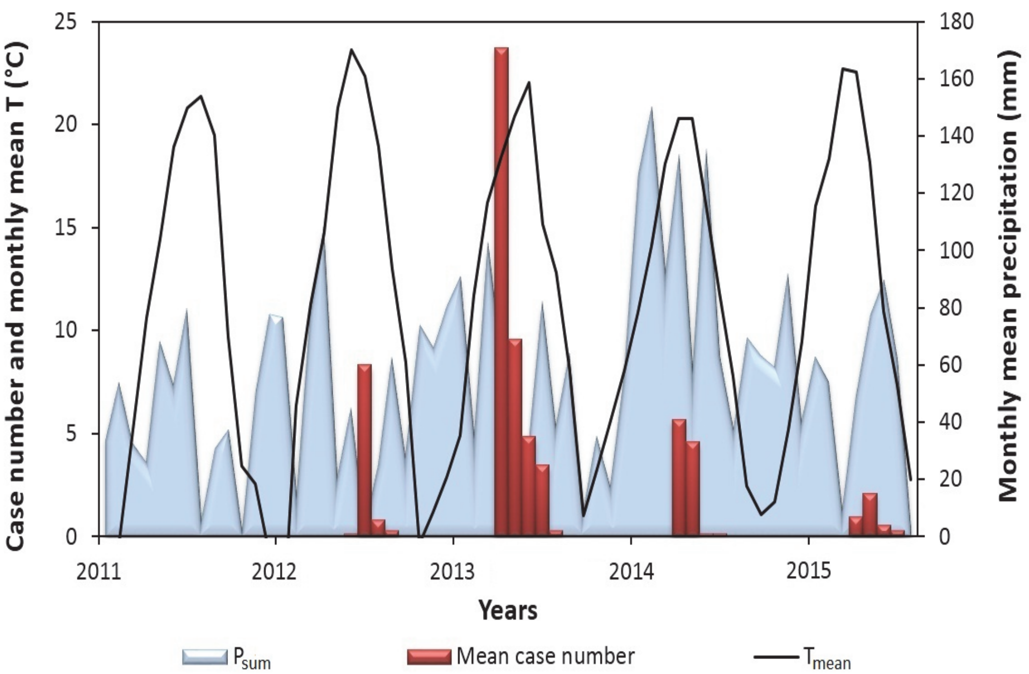

Fig. 10. The number of WNF cases from 2012 to 2015 in Serbia, and the run of the monthly mean temperature averaged to the grid of the affected areas of the country. The WNF data of 2011 is missing from the ECDC's public historical database.

Table 6. The results of the multiple regression analysis in case of Serbia

Correlation matrix	T_{mean}	P_{sum}	WNF
T_{mean}	1	–0.289	0.317
P_{sum}	–	1	–0.141
WNF	–	–	1
Multiple R^2=0.1031			
Adjusted Multiple R^2=0			

3.2.3. Romania

In Romania, the WNF season started in July (at and 21.6 °C) ended in November (at 5.3 °C). Most of the WNF cases (88.8%) occurred in August and September. (Fig.10) of which 48.5% in August. The first cases appeared in the warmest months and WNF season lasted from summer to the end of the vegetation season. In August and September during 2011–2015 in Romania the mean precipitation sum was 40.6 mm month^{-1} that is the 88.0% of the monthly mean precipitation sum (46.2 mm month^{-1}). In Romania, the peak of the annual case number occurred after the annual temperature maximum and precipitation minimum (*Fig. 11.*)

The mean monthly temperature was 17.0 °C, the mean air temperature weighted with the number of cases was 19.1 °C in the months of observations of the autochthon cases (maximum: 22.9 °C, minimum: 5 °C). The maximum length of the season was 3 months (*Fig. 12*).

According to the multiple regression analysis, very weak negative correlation exists between the mean monthly precipitation sums and the corresponding WNF case numbers. In contrast, moderate strong positive correlation was found between the mean monthly temperatures and WNF case numbers in Romania (*Table 7*).

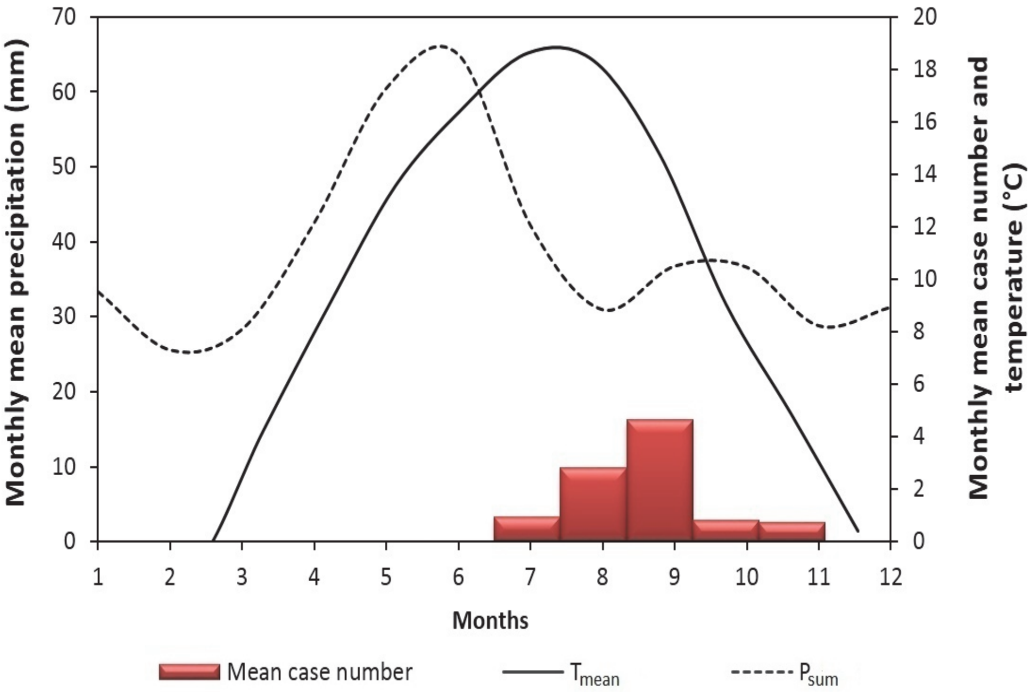

Fig.11. The mean monthly case numbers compared to the run of the mean monthly temperatures and the precipitation sums in Romania, 2011–2015.

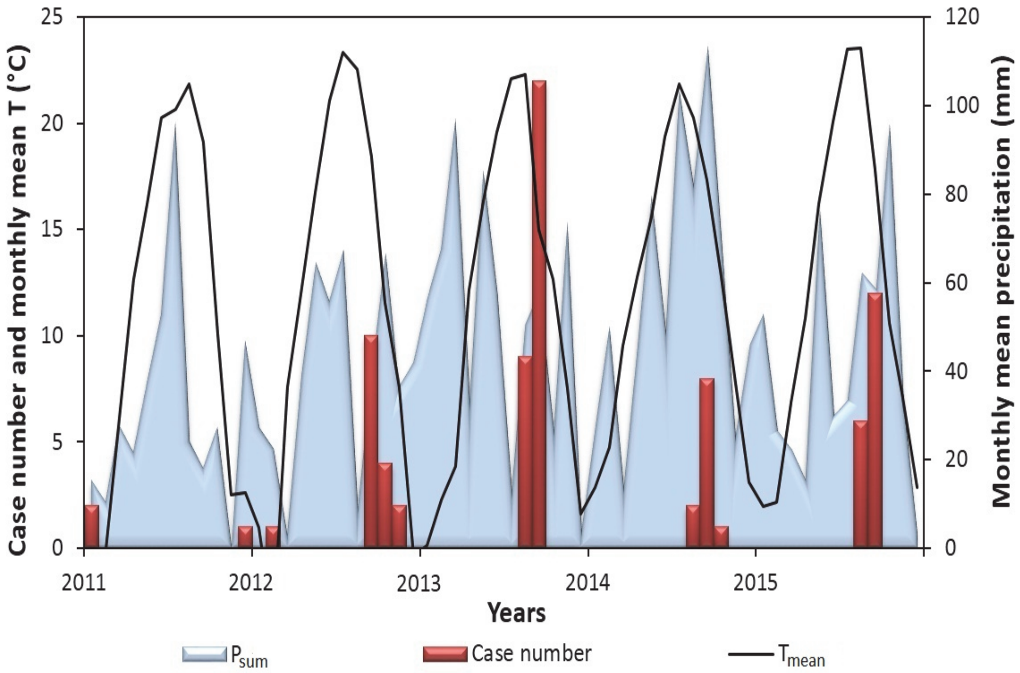

Fig.12. The number of WNF cases in 2011 to 2015 in Romania and the run of the monthly mean temperature averaged to the grid of the affected areas of the country.

Table 7. The results of the multiple regressions in case of Romania

Correlation matrix	T_{mean}	P_{sum}	Case
T_{mean}	1	0.573	0.522
P_{sum}	–	1	–0.183
Case	–	–	1
Multiple R^2=0.6182			
Adjusted multiple R^2=0.5333			

3.3. Comparisons

The mean monthly temperature in the months, when WNF cases were observed, was between 15.8–28.1 °C (SD: 4.73). The case number weighted mean of the monthly temperature during the WNF cases-related months ranged between 17.4 and 28.8 °C (SD: 4.40). West Nile fever seasons started in June or July in the studied countries at 18.9–24.0 °C mean monthly temperatures (average: 21.6 °C, SD: 1.65). The WNF season ended in October or November at 18.7–5.3 mean monthly temperatures (average: 10.1 °C, SD: 5.43). The highest summarized case numbers were observed in June (Serbia), August (Greece, Israel and the Palestinian territories, and Italy), or September (Hungary and Romania; *Table 8*).

In each of the studied countries positive correlations ($0.202<r^2<0.746$; average: 0.531, SD: 0.23) were found between the monthly mean temperature and the WNF case number sums. In contrast, in each of the studied countries negative correlations ($-0.131>r^2>-0.717$; average: –0.360; SD: 0.25) were found between the monthly precipitation sums and the WNF case number sums (*Table 9*).

Table 8. The mean temperature and the case-weighted temperature values under the months when WNF occurred and the average monthly temperature values at the start and the end of the seasons (GR: Greece, HUN: Hungary, IT: Italy, RO: Romania, ISR: Israel and the Palestinian territories, and SRB: Serbia)

Country	Tmean(°C)	Tmean weighted (°C)	T_{Start} (°C)	T_{End} (°C)
GR	21.8	24.4	24.0	14.9
HUN	16.7	17.4	21.3	6.1
IT	15.8	18.5	22.3	8.6
RO	17.0	19.1	21.6	5.3
ISR	28.1	28.8	21.6	18.7
SRB	17.3	19.5	18.9	7.0

Table 9. The regression coefficient according to the multiple regression results of the climatic variables and the case number values of the identical months (GR: Greece, HUN: Hungary, IT: Italy, RO: Romania, ISR: Israel and the Palestinian territories, and SRB: Serbia)

Country	R^2 T_{mean} (°C) x Case number	R^2 P_{sum} (mm) x Case number
GR	0.743	–0.717
HUN	0.202	–0.131
IT	0.661	–0.426
RO	0.522	–0.183
ISR	0.746	–0.566
SRB	0.317	–0.141

WNF cases mainly occur in the warm Mediterranean and the warm/hot summer continental areas of Europe. The warm or hot summer continental (Dfa, Dfb; e.g., the main part of Hungary) and the hot and dry summer Mediterranean climate (Csa; e.g., the main part of Greece or the north part of Israel), or the subtropical areas (Cfa; in the Mediterranean mountain ranges of Italy) are the most frequent climates where WNF occur in Europe. WNF is missing from the polar, alpine, and atlantic climate areas of the continent, excluding the maritime temperate regions (Cfb; southern slopes of the Alps in Italy). In Levant, WNF cases occur in hot summer Mediterranean (Csa); and warm semi-arid climates (Bsh; according to the Köppen-Geiger climate classification system (Table 10).

Table 10. Climate zones of the areas where WNF occurred in the studied countries according to the Köppen-Geiger climate classification system (BSh: warm semi-arid [hot steppe] climate, Csa: warm Mediterranean climate, Cfa: subtropical climate, Cfb: oceanic cimate, Dfa: hot summer continental climate, Dfb: warm summer continental climate; GR: Greece, HUN: Hungary, IT: Italy, RO: Romania, ISR: Israel and the Palestinian territories, and SRB: Serbia)

Country	Köppen-Geiger climate classification
GR	Csa, (Cfa, Dfb)
HUN	Dfb, (Dfa)
IT	Dfa, Cfa, Cfb, (Csa)
RO	Dfa, Dfb
ISR	Csa, BSh
SRB	Dfa, (Dfb)

4. Discussion

Temperature, rainfall, and humidity predominate the occurrence, morbidity and transmission dynamics of vector-borne diseases (*Githeko et al.*, 2000; *Gubler et al.*, 2001; *Gubler*, 1998), which is especially true for mosquito-borne infections (*Reiter*, 2001). Climate projections predict decreases in rainfall and temperature, and such changes have the potential to increase the risk of arbovirus transmission by increasing the distribution and abundance of vectors, and the length of mosquito vector and arbovirus seasons (*Russel*, 1998). *Whelan et al.* (2003) pointed out that rainfall is an important, positive risk indicator of mosquito abundance and mosquito-borne arbovirus incidence. In contrast, it was found that temperature and precipitation have different strength of impacts on the WNF case numbers in the Mediterranean and temperate climate countries. In general, monthly case number of WNF showed stronger correlations with the two climatic variables in the Mediterranean countries than in the continentals: strong positive correlations (Pearson's correlation coefficients were between 0.6 and 0.7) were found between the monthly mean temperatures and the WNF case numbers in the Mediterranean and weak to moderate strong (Pearson's correlation coefficients were between 0.2 and 0.5) positive correlations in the continental climate countries. Strong and moderately strong negative correlations (Pearson's correlation coefficients were between –0.7 and –0.4) were found between the monthly sum of precipitation and the WNF case numbers in the Mediterranean and very weak (Pearson's correlation coefficients were –0.1) negative correlations in the continental climate countries. These results are in accordance with the observations that under summer arid Mediterranean, climatic conditions, the positive effect of precipitation (mainly of heavy rainfalls) is more obvious and expressed on mosquito populations (*Paz* and *Albersheim,* 2008) than in the humid temperate regions, where the mosquitoes can find their breeding habitats without extreme rainfall events in summers (*Trawinski et al.,* 2008).

Platonov et al. (2008) found that WNF incidence was higher in the years with mild winter and hot summer. Rainy and cold summers, which occur in the Atlantic coasts are not favorable for mosquitoes. A very similar correlation was found in case of the distribution limiting factors of another Diptera vector group: the climatic requirements of *Phlebotomus* species. Sandflies avoid the Atlantic coasts of Western Europe due to the relatively cold, rainy summers, and only few sandfly species – e.g., *Phlebotomus perniciosus* Newstead (1911) – can tolerate the rainy summer climate of these areas (*Trájer et al.*, 2013). In Hungary, the effect of floods on the case number of WNF and the effect of river regulation on the mosquito abundance and diversity were demonstrated previously (*Trájer et al.*, 2014; *Trájer et al.*, 2015). The positive effect of temperature on the case number is clear and well-interpretable based on the ecology of the main vector *Culex* mosquitoes. Higher temperatures increase the mosquito activity and shorten the ontogeny time. Using climate envelope modeling, *Trájer et al.* (2014) found that global warming can enhance the European range of WNF.

As it was shown, the negative correlation between WNF case numbers and precipitation sums with a varying regression coefficient was observed in each country. This apparent contradiction between the findings of *Whelan et al.* (2003) and the results of this study partly can be resolved by the hypothesis, that not the higher mean precipitation itself, but the occasional heavy rainfalls can increase the case number of WNF under certain, mainly Mediterranean climatic areas. These occasional rainfalls do not increase significantly the summer mean precipitation sums providing a misleading consequence, that precipitation is a negative effector.

Summer drought has some potentially beneficial effects on mosquito populations. Water level decrease of different standing waters (e.g., backwaters and shallow lakes) during the dry period of summer may provide excellent habitats for mosquito larvae (*Shaman et al.,* 2002). Concerning even the 2 to 14 days latency, it can be concluded that low precipitation has no negative effect on the monthly mean WNF case number. In the Mediterranean and continental parts of Europe, summers are hot and dry excluding the westernmost part of the Mediterranean basin and the highest elevations of the Mediterranean mountain ranges. Nevertheless, the rapid evaporation of small and medium-sized waters in summer may result in the desiccation of the potential mosquito breeding habitats. Desiccating backwaters provide continuously warm mosquito larva habitats with flourishing algal communities, which conditions are highly preferable for several mosquito species. The desiccation of these larva habitats can explain the fact that the season of WNF is no longer in warmer climate conditions than in the colder parts of Europe. It is also known that the larvae of some mosquito species as *Aedes albopictus* Skuse (1894) or *Ochlerotatus sticticus* Meigen (1838) can survive the total desiccation of their habitats persisting in the wet mud of the former small waters (*Schäfer* and *Lundström,* 2006). Eutrophication cause the bloom of cyanobacteria and green algae, the accumulation of organic materials, while the consequent depletion of the soluble oxygen content is highly detrimental for fish predators. Algae and organic particles provide plentiful food for mosquito larvae, which organisms gain the oxygen directly from the atmospheric air storage. *Roehr* (2012) also found in the arid and semi-arid areas, where streams frequently dry up in summer, that the decreased water flow and the consequently appearing small waters provide ideal breeding habitats for mosquitoes. These facts can explain why in continental areas the hot and dry summers facilitate the outbreak of certain mosquito populations (*Reisen,* 1995). Shrinking water surfaces also can facilitate the contacts between vector mosquito and host bird populations (*Shaman et al.,* 2005). As already was mentioned, *Soverow et al.* (2009) and *Takeda et al.* (2003) found that in the USA, the average-exceeding precipitation conditions increase the WNF incidences. We should accept the conclusion of *Landesman et al.* (2007), that the effect of precipitation on mosquito populations and mosquito-borne diseases depends on the ecology of the mosquito vectors, the geographic location, and the characteristic climate of the area.

Temperature and precipitation affect the case numbers of mosquito-borne diseases in different ways. For example, the historical analysis of the effect of mean monthly temperature values and monthly precipitation sums on the autochthonous malaria cases of Hungary showed, that while temperature was the primary modulator of the relative annual run of the disease, the absolute malaria case number still depended on the summer precipitation patterns (*Trájer* and *Hammer,* 2016). The relatively late, mainly July and August onset of WNF remained a not completely understood phenomenon. Although birds are the main hosts of the virus, and the transmission of WNF from birds to humans requires a certain time through the increasing population of the infected mosquitoes in summer, the latency of the outbreak of the onset seems to be somewhat prolonged. It is known that, e.g., the former autochthonous malaria season reached its peak in June following the late spring-early summer boom of the potential mosquito populations in Hungary. It should be added, that the main vectors of malaria and WNF are not the same. This is an interesting outcome in the light of the observations that WNV plausibly can persist also in chronically infected vertebrates and hibernating female *Culex* mosquitoes (*Cornel et al.*, 1993; *Nasci et al.*, 2001 and *Taylor et al.*, 1956). This result is not supported by the always changing regional distribution of the disease in Hungary (*Trájer et al.*, 2014) and also in several parts of Europe, which partly can be the consequence of the re-introduction of the virus by migratory birds as it was hypothesized as an important determinant of the observed seasonality by *Chunikhin et al.* (1973), *Ernek et al.* (1977). The more rapid decrease of the case number compared to the mosquito activity may underline the role of human activity on the run of the case number and the temperature-dependent transmission rate of WNV.

5. Conclusions

Based on the Köppen-Geiger climate classification system, the hot summer continental and hot and dry summer Mediterranean climate zones are the most suitable areas for the West Nile virus and its vectors. The range of WNV avoids the boreal, oceanic, and mountainous climate zones of Europe. In contrast to the prior expectations, in each of the studied countries, negative correlations were found between the monthly precipitation sums and WNF case numbers. However, it can be rather the consequence of the fact, that, rainy summers occur in the Atlantic coasts of Europe, where summer temperatures are less than the activity and developmental optimum of the mosquito vectors, than a direct negative correlation between rainfall and case number. Although heavy rainfall events and the consequent floods may have positive influence on the population size of mosquitoes, in each of the studied countries, negative correlations were found between WNF incidences and precipitation sums. The lengths of the main part of the WNF seasons are similar and not clearly dependent on the geographical position of a given country, but in fact, in Israel and the Palestinian territories, the

WNF season starts two months earlier than in Hungary. It is plausible, that the annual migration activity of birds and the activity of the mosquito vectors are also strongly influenced by the length of the daytime hours.

Acknowledgement: The author acknowledges the E-OBS dataset from the EU-FP6 project ENSEMBLES (http://ensembles-eu.metoffice.com) and the data providers in the ECA&D project (http://www.ecad.eu)" Haylock, M.R., N. Hofstra, A.M.G. Klein Tank, E.J. Klok, P.D. Jones and M. New. 2008: A European daily high-resolution gridded dataset of surface temperature and precipitation. J. Geophys. Res (Atmospheres), 113, D20119, doi: 10.1029/2008JD10201. The study was supported by EFOP-3.6.1-16-2016-00015.

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