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Seasonality and geographical occurrence of West Nile fever and distribution of Asian tiger mosquito

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Abstract—The importance and risk of emerging mosquito borne diseases is going to increase in the European temperate areas due to climate change. The present and upcoming climates of Transdanubia seem to be suitable for the main vector of Chikungunya virus, the Asian tiger mosquito, *Aedes albopictus* Skuse (syn. *Stegomyia albopicta*). West Nile fever is recently endemic in Hungary. We used climate envelope modeling to predict the recent and future potential distribution/occurrence areas of the vector and the disease. We found that climate can be sufficient to explain the recently observed area of *A. albopictus*, while in the case of West Nile fever, the migration routes of reservoir birds, the run of the floodplains, and the position of lakes are also important determinants of the observed occurrence.

Key-words: climate change, climate envelope model, vector-borne diseases, *Culex*, mosquitoes, *Aedes albopictus*, West Nile fever, Chikungunya disease

1. *Introduction*

1.1. Climate change and emerging mosquito-borne diseases

Within the class Insecta, the order Diptera has the greatest vectorial potential (e.g., flies, sand flies, mosquitoes) as vectors of important human infectious diseases. The most important family is Culicidae with such important genera as *Aedes* and *Culex*. Vector-borne diseases are sensitive to climatic conditions (*Githeko et al.*, 2000; *Harwell et al.*, 2002*; Hunter*, 2003; *Rogers* and *Randolph*, 2006). While the length of every development stages varies among species, it is common that it is greatly affected by the ambient temperature (*Rueda et al.*, 1990; *Bayoh* and *Lindsay*, 2003, 2004; *Teng* and *Apperson*, 2000). Global warming can cause the expansion and the increasing abundance of insect populations (e.g., pests of plants) by changing the length of vegetation period and moderation of the winter colds throughout Europe (*Cannon*, 2004; *Dukes* and *Mooney*, 1999; *Ladányi* and *Horváth*, 2010). Climate change can facilitate the migration of these arthropod vectors to north (*De la Roque et al.*, 2008). The projected warmer conditions are favored by mosquitoes and their parasites (*Epstein et al.*, 1998; *Reiter*, 2001). Since the adult mosquitoes have good flying ability, their expansion can be rapid. They are vectors of many serious viral infection, such as West Nile fever (hence: WNF) and Chikungunya disease which are re-emerging or emerging diseases in the Northern Hemisphere (*Meckenzie et al.*, 2004; *Reiter et al.*, 2006). The transmitters and main sources of the disease are *Culex* species.

While the potential mosquito vectors of West Nile virus (hence: WNV) live in the entire holarctic ecozone, theoretically West Nile virus may be endemic in every part of Eurasia and North America. In contrast to the theoretical investigations, the historical presence of WNF was less abundant. From this reason we aimed to study the climatic requirements of the disease itself and not those of the potential vectors. According to *Spielman* (2001), *Culex* mosquito populations begin to proliferate when the water temperature exceeds 15 °C during June, so the first stable week, when the ambient temperature reaches the 15 °C, can be used as the start of the WNF season.

Many of the potential vectors of WNV are native in Europe. As it is expected, the climate in the Carpathian Basin will be warmer, more arid, and will have extreme rainfalls more frequently in the colder half-year (*Bartholy et al.*, 2007). The increased frequency of heavy rainfall events, with consequential floodings may increase the incidence of mosquitoe-borne diseases and water-borne diseases (*Hunter*, 2003).

Chikungunya virus belongs to the family Togaviridae and is usually transmitted to humans by *Aedes* mosquitoes (e.g., the Asian tiger mosquito, *Aedes albopictus* Skuse (1894). Before 2006, Chikungunya disease and the *Aedes* mosquitoes were mainly reported from the sub-saharan Africa, the

Hindustan Peninsula, and Southeast Asia, but now the vector, *Ae. albopictus*, is presents widely in the Mediterranean Basin (in Spain, France, Italy, Slovenia, Croatia, Serbia, Bosnia and Herzegovina, Albania, and Greece).

Our aim was to study the influence of the ambient temperature and floods on WNF case number and to create a model to take into consideration the potential future distribution of West Nile virus and *Ae. albopictus* mosquito.

1.2. Climate envelope modeling

Ecological modeling methods are utilized in ecology to predict how species, diseases, or ecological structures will response to global warming or other changes of the ecological environment. To project the possible impact of climate change on the distribution of the selected vector, *Ae. albopictus*, and the occurrence of the disease WNF we used climate envelope modeling (CEM) method (*Hijmans* and *Graham*, 2006). *Fischer et al.* (2001) also used CEM to model the future expansion of *Ae. albopictus*. CEM is based on statistical correlations between the observed distributions of species (e.g., *Aedes albopictus* mosquito) or occurrences of diseases (e.g., WNF) and environmental variables to define the tolerance, the limiting ecological factors (e.g., minimum/maximum of temperature, precipitation, length of the vegetation season) of the species or the disease (*Guisan* and *Zimmermann*, 2000; *Elith* and *Leathwick*, 2009). Based on this bioclimatic envelope, using a selected climate scenario, one can predict the probable future range of the species/disease. The hidden and sometimes arguable idea of the CEM is assuming that climate plays primary role on the present and future distribution of the species (*Czúcz,* 2010). For example, in the case of a vector-borne infectious disease, the long-distance transport, the migrating workers and traveling can play a very important role as the determinant of the real geographical occurrence (*Walther et al.*, 2009; *Neghina et al.*, 2009).

1.3. Migrating birds, rivers, wetlands, and West Nile virus

Not only climatic factors determine the distribution of WNF. The principal vectors of the West Nile virus are *Culex pipiens* complex and *Culex modestus* (in Europe, *Culex* species and ticks in Russia also ticks, while migrating birds are the most important reservoirs and propagators of WNV) (*McLean et al.*, 2001; *Reed et al.*, 2003). Mosquitoes transmit the virus to birds, and then the next generation of the virus will infect the biting mosquitoes.

The mean water level and the changes of the water level of the rivers may have an important influence on the mosquito season.

WNV (a member of Flaviviridae) originally was autochthonous in Africa before the 1990's and it was first isolated in 1937, in the Sub-Saharan West Nile territory of Uganda. Then the virus was isolated from humans, birds, and mosquitoes in Egypt (Nile delta) in the early 1950s (*Hubálek* and *Halouzka*, 1999). In Europe it appeared at first, in Albania, 1958 (*Bárdos et al.*, 1959) and many of the early larger outbreaks were reported from the river deltas: from the Rhone delta in 1963 (*Hannoun et al.*, 1964), the Rumanian Danube delta in 1971 (*Topciu et al.*, 1971), and the Volga Delta in 1964 (*Chumakov et al*., 1964).

Bird migration is the most important way of WNF/WNV introduction to the temperature areas (*Malkinson et al.,* 2002; *Reed et al.*, 2003). It is clear that rivers and riverbanks, coastal plains and deltas are the gathering and feeding places of migrating birds (*Malkinson et al.*, 2002). In Hungary also most of the cases occurred near to riversides, mainly between the riverbank of Tisza, Zagyva, and Rába, as it was seen in 2008. (*Krisztalovics et al*., 2008).There are 3 main migration routes between Africa and Eurasia (via Gibraltar, via Sicily, via Sinai) (*Fig. 1A*), and one of them (*Fig. 1B*, red lines) makes connection between Eurasia and the eastern sub-saharan part of Africa, e.g., the West Nile territory (*Fig. 1B*), which is the most important migration route of white stork (*Ciconia ciconia* Linnaeus (1758) (*Berthold*, 2004), which bird species itself an important introducer of WNF (*Malkinson et al.*, 2002). It seems that migratory birds are the most important introductory hosts for the virus (*Rappole* and *Hubálek*, 2003). According to *Jourdain et al*. (2007), the risk for introduction of African pathogens, such as WNF into Mediterranean wetlands may be the highest from March to July, which is in accordance with the spring migration and breeding for birds.

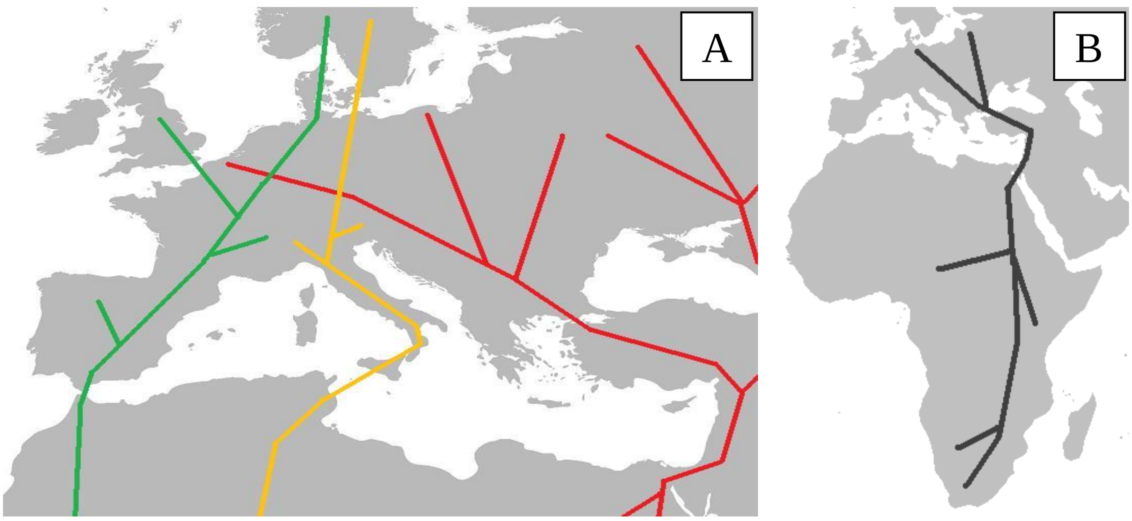

*Fig. 1.***A**: The simplified scheme of the main migration routes of birds between Africa and Europe. Red: Via Sinai per the Middle East from East Africa to Central and Eastern Europe, Yellow: Via Sicily per the Apennine Peninsula, Green: Via Gibraltar per the Hispanic Peninsula. The composite figure mainly was based on the migration routes of different birds of the homepage Global Register of Migratory Species. **B**: The right picture shows the eastern migration scheme route of white stark (Global Register of Migratory Species, *Ciconia ciconia*). Note, that the West Nile territory is an important part of their migration route.

1.4. The threshold minimum temperature of West Nile season

Since according to *Kilpatrick et al*. (2008), *Reisen et al.* (2006), and *Spielman* (2001) the temperature derived transmission of WNV from *Culex* mosquitoes to humans may be between 14–15 °C, we handle the 15 °C as the minimum temperature limit of the WNF season.

2. Materials and methods

2.1. Data sources

2.1.1. West Nile data of Hungary for the period of 2004–2010

The Hungarian WNF data was derived from the Hungarian Epidemiological and Surveillance System and Epinfo (2010A), Epinfo (2010B), and *Krisztalovics et al.* (2008). We could gain the geographical distribution data of the years 2008, 2010, 2011, and 2012.

2.1.2. The hydrological data of the river Tisza

The hydrological data of the river Tisza in the period of 2007–2012 were retrieved from the National Water Warning Network of Hungary (Hydroinfo). We averaged the monthly water levels of May to September. To depict the annual amplitude of the water regime, we used the difference between the annual maximum and minimum water levels.

2.1.3. Climate data

We used the REMO climate model (ENSEMBLES, 2013), which is nested into the ECHAM5 global climate model *(Roeckner et al*., 2003, 2004) and is based on the IPCC SRES A1B scenario. The A1 scenarios suppose rapid economic and population growth, and rapid global transfer of technologies and knowledge (*Nakicenovic et al*., 2000).

1961–1990 is the reference period of the REMO model, and the periods of 2011–2040 and 2041–2070 are the selected prediction periods. REMO has 25 km horizontal resolution and the entire Europe is within its domain. In our model we used about the 80% of the points of REMO.

2.1.4. Distribution and occurrence data

Since the model studied the climate requirements only of the European populations – the North African distribution segments were excluded –, it was able to project the shift of this part only. The distribution data of *A. albopictus* was derived from the VBORNET database of the European Centre for Disease

Prevention and Control according to stage in September 2012 (*Medlock et al*., 2012).

The occurrence of WNF was also derived from European Centre for Disease Prevention and Control homepage and from the European Disease and European Centre for Disease Prevention and Control (ECDC) homepage (ECDC West Nile Fever Maps 2012 and 2011). Furthermore, we also used a publication of the Eurosurveillance journal (*Krisztalovics et al.*, 2008).

The Chironomidae (family Chironomidae) mosquito geographical presence data was derived from *Móra* and *Dévai* (2004). The original checklist and map was based on the review of the faunistical data in the period of 1990–2004. In these 104 years long period, 228 species were observed in Hungary and 98 species are expected to occur (*Móra* and *Dévai*, 2004).

We did not use weighting process, the distribution/occurrence maps of the mosquito and WNF was reduced to simple presence-absence maps. The regions entitled as 'indigenous' and 'recently present' of *Aedes albopictus* while in the case of WNF, the 'area reporting cases in 2012', 'area reporting cases in 2011', 'area reporting cases in 2010' were selected to be digitized. All the data were based on the NUTS3 regions, which are the third level public administration territories of the European Union. After a georeferencing process with third order polynomial transformation, the digitization of the bitmap-format distribution maps were realized with the assistance of the digital NUTS3 polygon borders (GISCO, 2013).

2.1.5. Population of the Hungarian regions

While we studied the regional WNF incidence rate of 2008, 2010, 2011, and 2012 (5-year-long short interval), we could use the population numbers of the year 2012. We retrieved the statistical data from the Central Statistical Office of Hungary (KSH, 2012).

2.2. Statistics

We applied descriptive statistics using SPSS 10.0 and Excel 2010 softwares.

2.3. Modeling method

According to *Thuiller et al*. (2004), climate has the greatest influence on forming the geographical distribution of the species in Europe. We used three physical (climate) factors averaged in the 30-year periods: the monthly mean temperature (T_{mean}, °C), the monthly minimum temperature (T_{min}, °C), and the monthly precipitation (P, mm) of the 12 months. This means 3×12 factors in the model.

Cumulative distribution functions were calculated by PAST statistic analyzer (*Hammer et al*., 2001) for the selected 3×12 climatic parameters (T_{mean},

T_{min}, P). 10–10% from the extrema in the case of *Ae. albopictus* and 5–5% from the extrema in the case of WNF were neglected from the climatic values found within the observed distribution/occurrence. The selection of the amount of percentiles to be left from the climatic values was based on our former studies. The aim was to restrict the false positive error of the model result in a reasonably degree. We refined the climatic data by the inverse distance weighted interpolation method of ESRI ArcGIS 10 software. The modeling steps were the follows: first, the grid points within the distribution were quoted; second, the percentile points of the climatic parameters were calculated; third, the suitable percentiles of the climatic parameters were chosen; fourth, modeling phrases (3 strings) were created by string functions of Microsoft Excel 2007 for the three modeling periods; fifth, the ranges were selected where all the climatic values of the certain period were between the extrema selected in step 3.

3. Results

3.1. West Nile fever in the period of 2004–2012 in Hungary

3.1.1. Statistics

In Hungary, West Nile fever is recently endemic; 34 cases were reported in the period of 2004–2009 (*Krisztalovics et al.*, 2011; Epinfo, 2010A), 11 cases in 2010 (Epinfo, 2010B), 4 cases in 2011 and 12 cases in 2012 (ECDC, West Nile fever maps 2012). In the period of 2004–2012 WNF showed an increasing trend, but the annual incidence was low and highly variable (0–19/10 million) from year to year (*Fig. 2*), so the trend was not significant at 5% significance level.

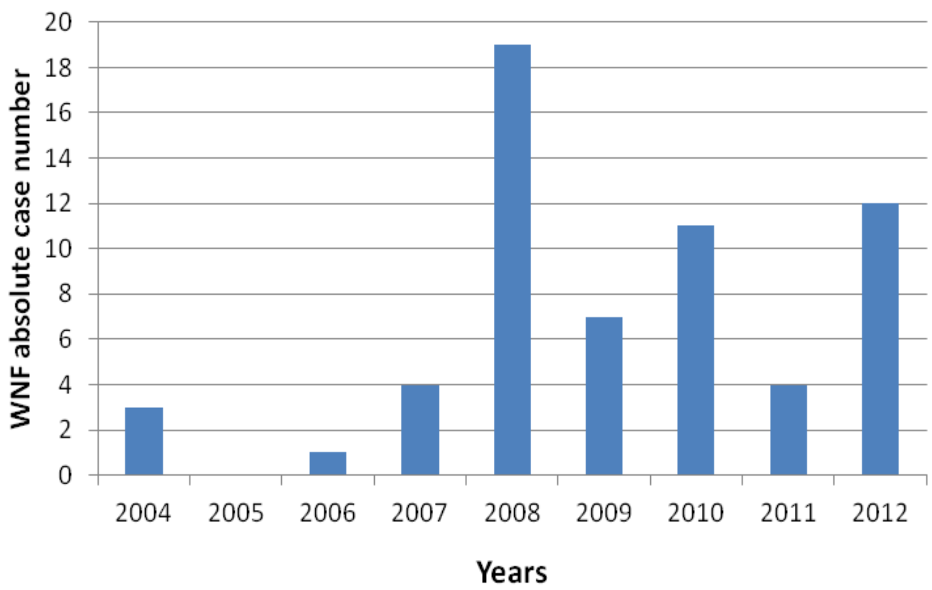

Fig. 2. The absolute annual WNF case number in the period of 2004–2012 in Hungary.

3.1.2. Regional distribution of the WNF incidences

The Hungarian regions correspond to the NUTS 2 statistical regions of the European Union. In 2008 and 2010 –2012 (the geographical data of 2009 is missing), the highest WN incidence rates were observed in northern Great Plain (NGP; $6.6*10^{-6}$), southern Great Plain (SGP; $5.24*10^{-6}$), southern Transdanubia (STD; $5.2*10^{-6}$), and western Transdanubia (WTD; $5.01*10^{-6}$). In central Transdanubia (CTD; $3.62*10^{-6}$), northern Hungary (NH; $2.48*10^{-6}$), and central Hungary (CH; $2.41*10^{-6}$), the WNF average incidence of this 3 regions were about the half of the average incidence rate of NGP, SGP, STD, and WTD. The changing WNF incidence rate did not show any significant trends, and the geographic distribution of the cases showed that the focuses of occurrence changed from year to year (*Fig. 3*).

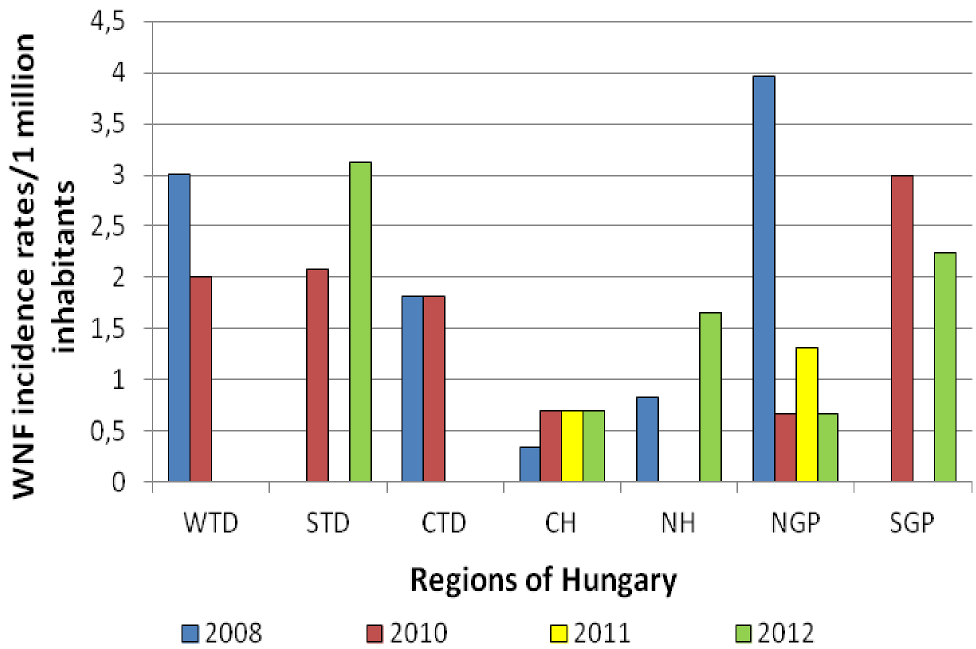

Fig. 3. WNF incidence rates per 1 million inhabitants in the different Hungarian regions in 2008 and 2010–2012 according to the population numbers of 2012. WTD=western Transdanubia, STD=southern Transdanubia, CTD=central Transdanubia, CH=central Hungary, NH=northern Hungary, NGP=northern Great Plain, SGP=southern Great Plain.

3.1.3. Seasonality

WNF showed a clear seasonality (*Fig. 4*). About the ¾ of the cases occurred in August and September. In most of the years the season started in late July (e.g., in the 30th week in 2010) or August (e.g., in 2007, 2008). No cases were recorded between December and March and in June.

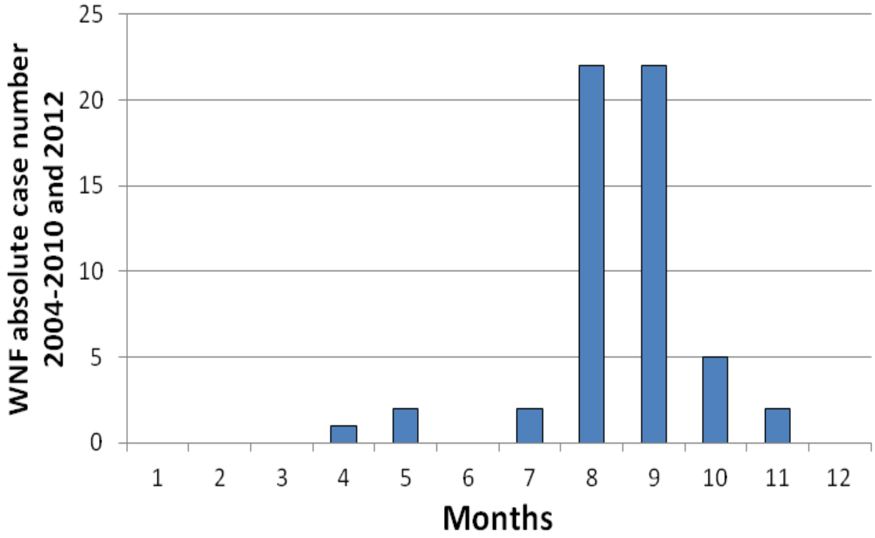

Fig. 4. The seasonal distribution of the WNF cases in Hungary in the period of 2004–2010 and 2012.

3.1.4. Ambient mean weekly temperature and WNF

In 2004–2010 and 2012, the 66.66% of the first symptoms of the disease cases occurred above 19 °C and 84,84% above 16 °C. The highest case numbers were observed between 21–21.9 °C weekly mean ambient temperatures (*Fig. 5*). No cases were observed under 10 °C. Note, that the incubation period of the infection with WNV is thought to range from 3 to 14 days (CDC), but the probability distribution of the latency interval is not known.

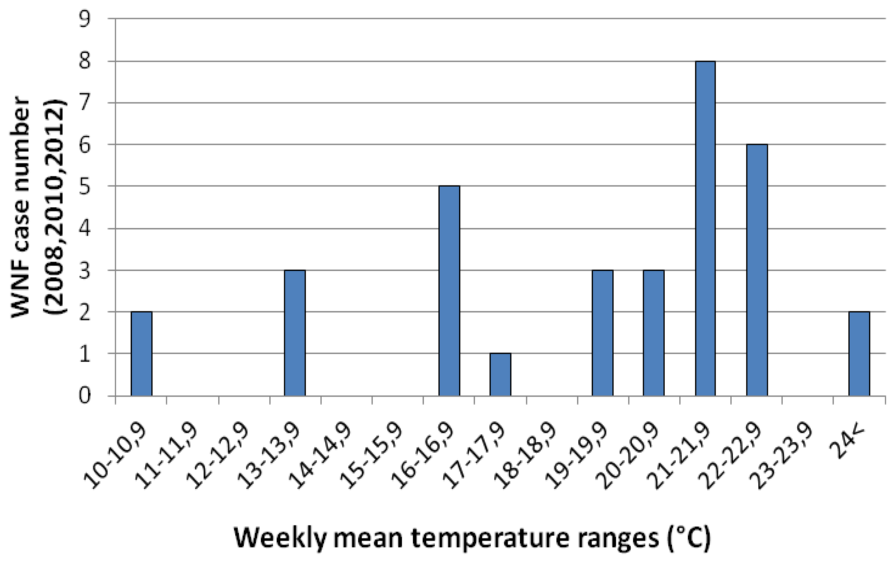

Fig. 5. The frequency histogram of weekly ambient temperatures of 2008, 2010, and 2012, and the number of the WNF cases.

3.1.5. West Nile season

The averaged ambient weekly temperature of the 4 previous weeks before the first WNF case was 21.6 °C in 2008 (*Fig. 4*), 23.82 °C in 2010 (*Fig. 5*), and 23.65 °C in 2012 (*Fig. 6*). 78.6% of the cases in the period of 2004–2010 and 2012 (the weekly data of 2011 is missing) occurred in August and September. In 2008 and 2010 the WNF cases terminated, when the weekly mean temperature dropped below 14.3–13.7 °C. In 2012 after the penultimate case, the ambient temperature dropped below 13.7 °C and the last case occurred, when the mean temperature was 7.5 °C. 19 weeks passed from the first stable week with 15 °C or more ambient temperature to the first WNF case 2008, 14 in 2010, and 13 in 2012.

As we mentioned in Section 2, we selected the weeks of the mean ambient temperature more than 15 °C as the season of *Culex* mosquitoes. According to these observations, we practically handled the period of May to September as the main time of the *Culex* season.

The *Culex* season started in the 18th week of the year (in mid-April) in 2008 and terminated in the 37th week in the first quarter of September. In 2008 the observed WNF season exceeded the theoretical *Culex* season by 2 weeks (*Fig. 6*).

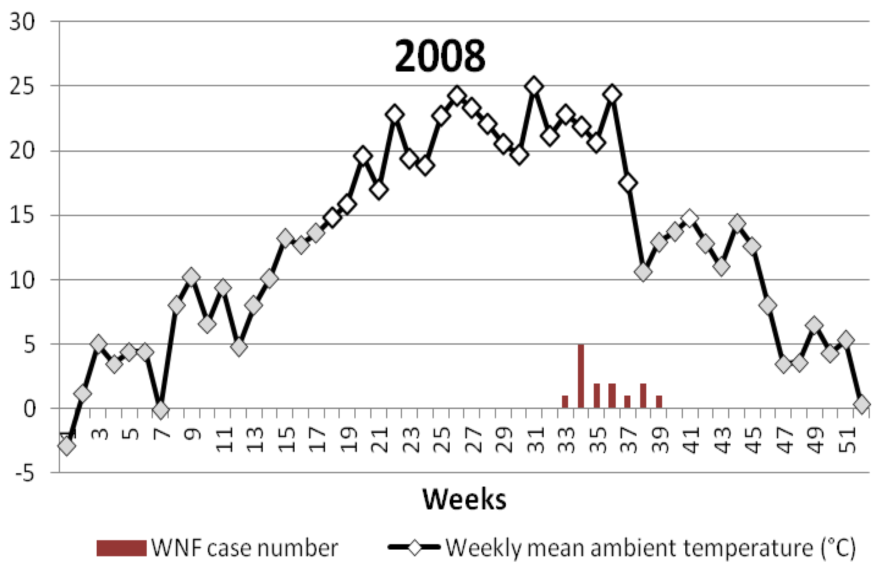

Fig. 6. The weekly ambient temperatures in 2008 and the absolute number of WNF cases. Light gray points mark the weeks, when the ambient temperature was less than 5 °C.

In 2010, the *Culex* season started in the 20th week in the start of May and terminated in the 35th week in late August. In 2009, the last case occurred in the last week of the theoretical season (*Fig. 7*).

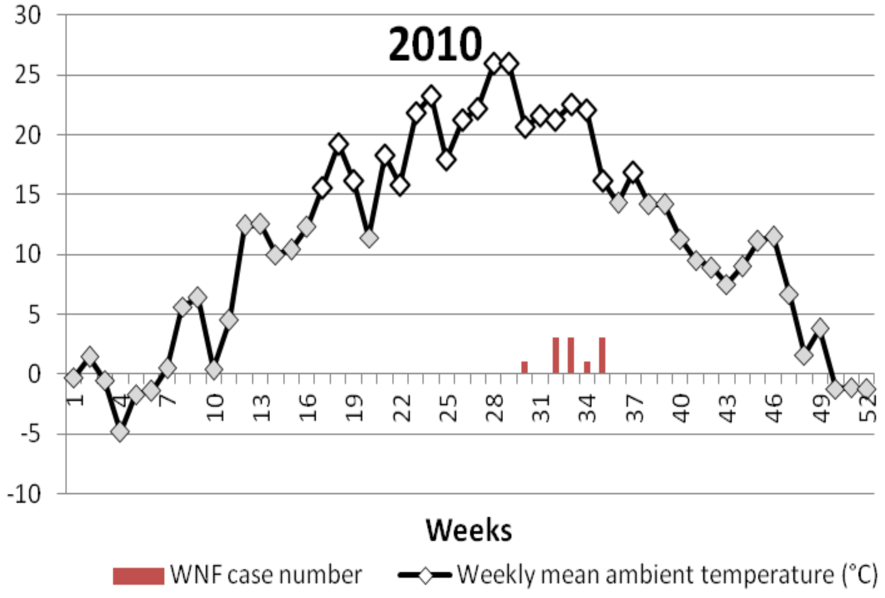

Fig. 7. The weekly ambient temperatures in 2010 and the absolute number of WNF cases. Light gray points mark the weeks, when the ambient temperature was less than 5 °C.

In 2012, the season started in the 16th week and terminated in the 43rd week in late October. In 2012, the last observed case exceeded the theoretical season by 4 weeks, the previous case occurred 1 week before the theoretical end of the mosquito season (*Fig. 8*).

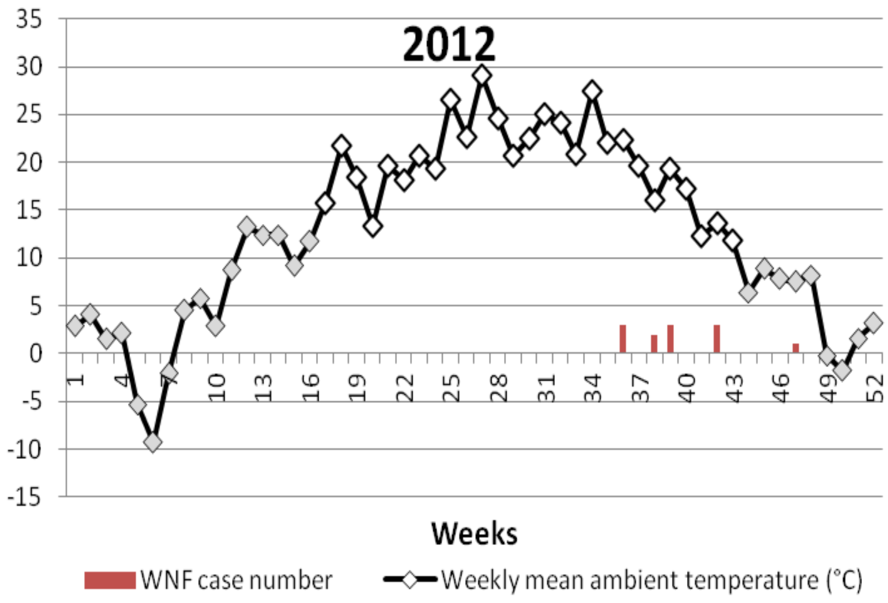

Fig. 8. The weekly ambient temperatures in 2012 and the absolute number of WNF cases. Light gray points mark the weeks, when the ambient temperature was less than 15 °C.

3.2. Floods and WNF in Hungary

3.2.1. Presence of Chironomidae mosquitoes as wetland indicators and WNF

From the first observed human WNF in Hungary in 2004 most of the cases were tied to the rivers Tisza, Raba, Drava, Zagyva, Körös, and Hernád channels (e.g., East Main Channel), and lake Balaton. The river Danube had a less importance. For example from January 2008 to September 2008, 8 WNF cases occurred in the Tisza valley and only 2 cases were observed in the Danube valley. Only 1–2 cases per year were matched to the river Danube. Since before 2007 the WNF level were very low (in the period 2004–2006 only 4 cases were observed), we used the period 2007–2012.

Despite the fact, that Chironomidae (non-biting) mosquitoes are not the vectors of WNF, this species are tied to wetlands, rivers in Hungary since the larvae live in aquatic or semi-aquatic habitats (*Móra* and *Dévai*, 2004). They are good water quality indicators as well, while the larvae can live in polluted waters (*Lindegaard*, 1995). The larvae of *Culex* mosquitoes are also live in aquatic habitats. In 2008, most of the WNF cases between May and September were linked to similar habitats (rivers, lakes, channels) as non-biting mosquitoes (*Fig. 9*).

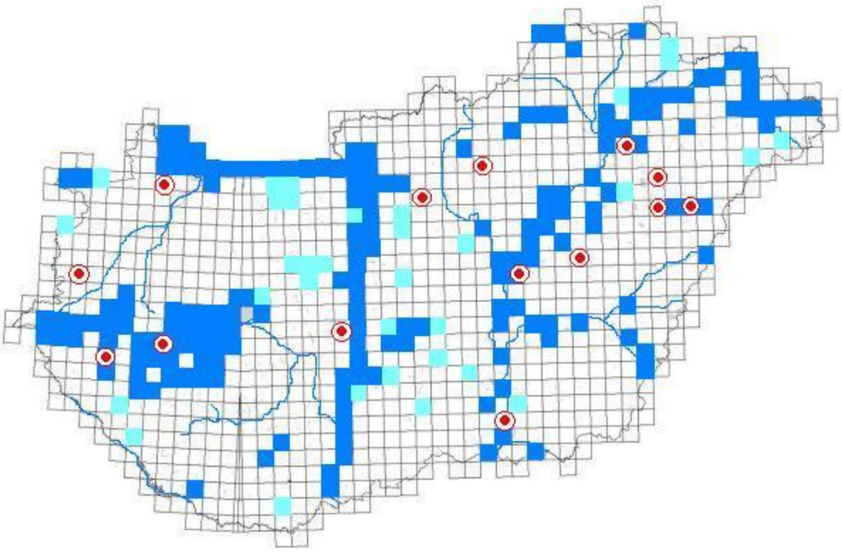

Fig. 9. The confirmed presence of Chironomidae mosquitoes (dark blue), the non-confirmed, but expected presence of Chironomidae mosquitoes (light blue) (according to *Móra* and *Dévai*, 2004), and the occurrence of WNF in 2008 between May and September (n=14) in 2008, Hungary (red circles within red spots; according to *Krisztalovics et al*., 2008).

3.2.2. Amplitude of the water level changes of the rivers Tisza and Danube

The mean of the annual maximum and minimum water levels of river Danube was Δ=556 cm, since in the case of river Tisza it was 1.6 times higher: Δ=899 cm. (*Fig. 10*).

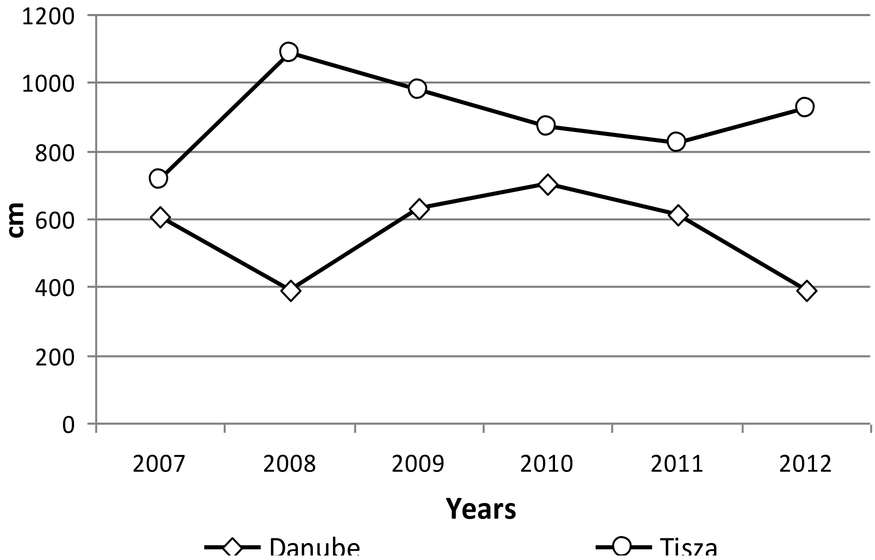

Fig. 10. Differences between the annual maximum and minimum water levels of the rivers Danube and Tisza in the period of 2007–2010.

3.2.3. Water level of the river Tisza at Szolnok (2007–2012)

Since over the Danube the number of the observed WNF cases was negligible under the studied period, we selected the river Tisza as a typical representative of the rivers in the Carpathian Basin, while the entire drainage basin of Tisza is within the Carpathian Basin, and the water regime of the Tisza is the consequence of the previous and the same year's precipitation patterns of the Carpathian Basin.

The average water level of Tisza between May and September in Szolnok (according to the long-time average, *l*) was the following: –71 cm in, 118.6 cm in 2008, –108 cm in 2009, 454.6 cm in 2010, –40.2 cm in 2011, and –99.6 cm in 2012. We calculated the own mean of the 6-year-long period, which was 42.4 cm. Thereafter, we calculated the water level differences from the mean: –113.4 cm in 2007, 76.2 cm in 2008, –150.4 cm in 2009, 412.2 cm in 2010, –82.6 cm in 2011, and –142 cm in 2012. After this process we calculated the percent values according to the absolute range –150.4 cm in 2009, 412.2 cm in 2010, absolute range 562.6 cm as 100%: –20.16% in 2007, 13.54% in 2008, –26.73% in 2009, 73.26% 2010, –14,68% in 2011, and –25.28% in 2012.

3.2.4. Changes in the WNF case number (2007-2012)

The case numbers of the years were the following: n=4 in 2007, n=19 in 2008, n=7 in 2009, n=11 in 2010, n=4 in 2011 and n=12 in 2012. The mean of the WNF case numbers was 9.5 cases per year in the period. We calculated the differences of the cases from the mean: –5.5 in 2007, 9.5 in 2008, –2.5 in 2009, 1.5 in 2010, –5.5 in 2011 and 2.5 in 2012. After this process we calculated the percent values of the differences according to the absolute range of the maxima and the minima of the WNF cases (–5.5 [2007, 2011]; 9.5 [2008]; absolute range)=15 as 100%): 36.6% in 2007, 63.3% in 2008, –16.6% in 2009, 10% in 2010, –36% in 2011 and 16.6% in 2012.

The comparison of the changes of the water level of the Tisza in Szolnok and the WNF cases- showed that five years from the six the sign (less or more than the mean, 0%) of this percent values changed simultaneously except the year 2012 (*Fig. 11*). The relative risk to the above-average number of WNF cases was 4 times higher when the mean level of the river Tisza was higher than the mean of the studied six years (WNF > mean and water level > mean: 2 years, WNF < mean and water level > mean: 0 year, WNF > mean and water level < mean: 1 year, WNF < mean and water level < mean: 3 years).

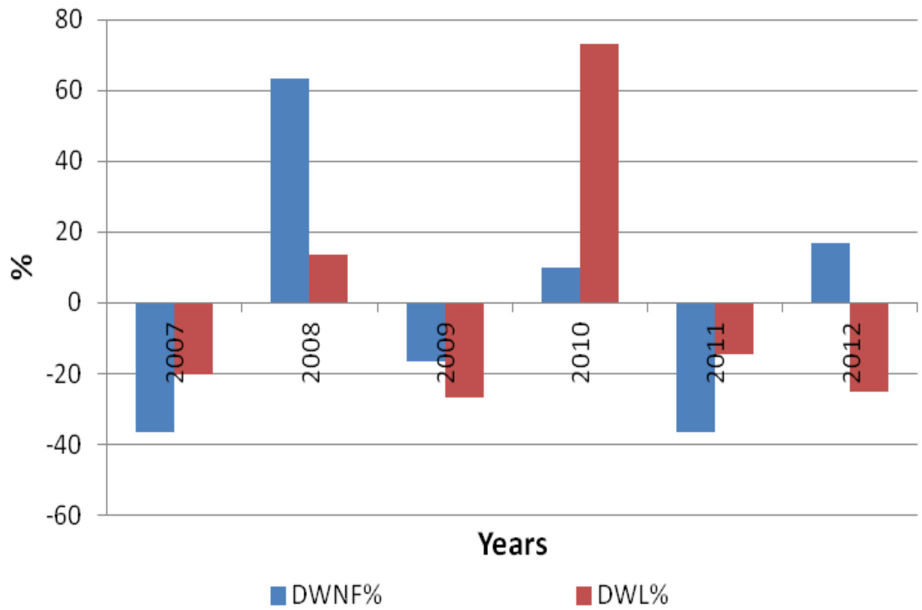

Fig. 11. The percent difference of the May-September mean water level of the period 2007–2012 within the absolute water level range of the river Tisza at Szolnok (DWL%) and the percent difference of the annual WNF case number in Hungary within the absolute water level range of the maxima and minima of the case inerval (DWNF%) in the period of 2007–2012.

3.3. *Model results*

3.3.1. *The predicted occurrence of West Nile fever*

The observed and predicted potential distributions of the WNF are shown in *Fig. 12*. The recent occurrence of visceral WNF is mostly restricted to the eastern Mediterranean areas and Eastern Europe. The model predicted the potential occurrence of WNF with the sporadic cases in the reference period to be greater than the observed current occurrence. The major difference can be seen in Spain. Future expansion is expected principally in Asia Minor, the Carpathian Basin, and the Balkan Peninsula, but the set of the affected countries is much larger: Spain, France and Hungary (mainly in the far future period), Serbia, Macedonia, Bulgaria, Romania, Ukraine, and Turkey. Considering the current occurrence and the model result, east-southeast Europe and the Carpathian Basin are highly vulnerable areas. In the western parts of Europe, the primary limiting value is the minimum temperature in July (T_{min} of July more than 20.9 °C). It seems that the continental climate with warm summers and September are favor of West Nile disease (T_{mean} from June to September should be more than about 22 °C). WNF need for moderate summer precipitation (P in July is less than about 80 mm).

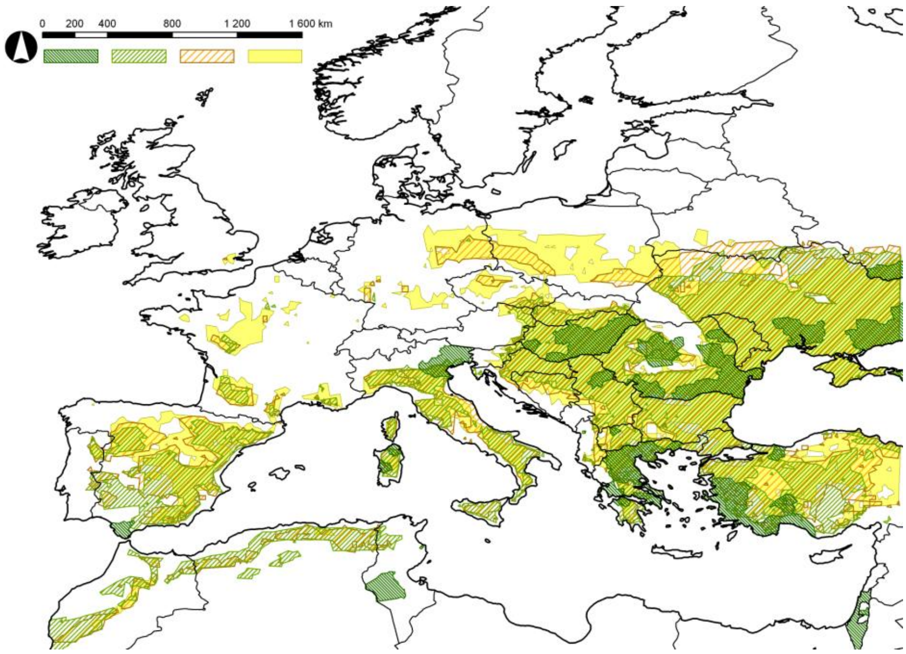

Fig. 12. The recent (2010–2012) distribution of WNF (dark green according to the VBORNET database), the potential distribution area for the reference period (1961–1990, light green), and the projected future distribution for the periods of 2011–2040 (orange) and 2041–2070 (yellow)

3.3.2. Predicted distribution of the Ae. albopictus mosquito

Observed and predicted potential distribution of the aggregation of the Asian tiger mosquito species are shown in *Fig. 13*. The Mediterranean, most of the territories of Italy, and some regions of the Balkan and Spain with Mediterranean climate are included in the observed distribution. The modeled potential distribution seems to be greater in Western Europe and in the north Balkan, and some parts of the Carpathian Basin. In the near future period expansion is predicted mainly in France, Spain, Croatia, Serbia, and Hungary. In the period of 2041–2070, significant expansion is projected in the northern parts of France. The primary limiting value is the minimum temperature in January (T_{min} should be more than about –2 °C), *Ae. albopictus* prefers the relatively dry summers (*P* in July is less than about 6 mm).

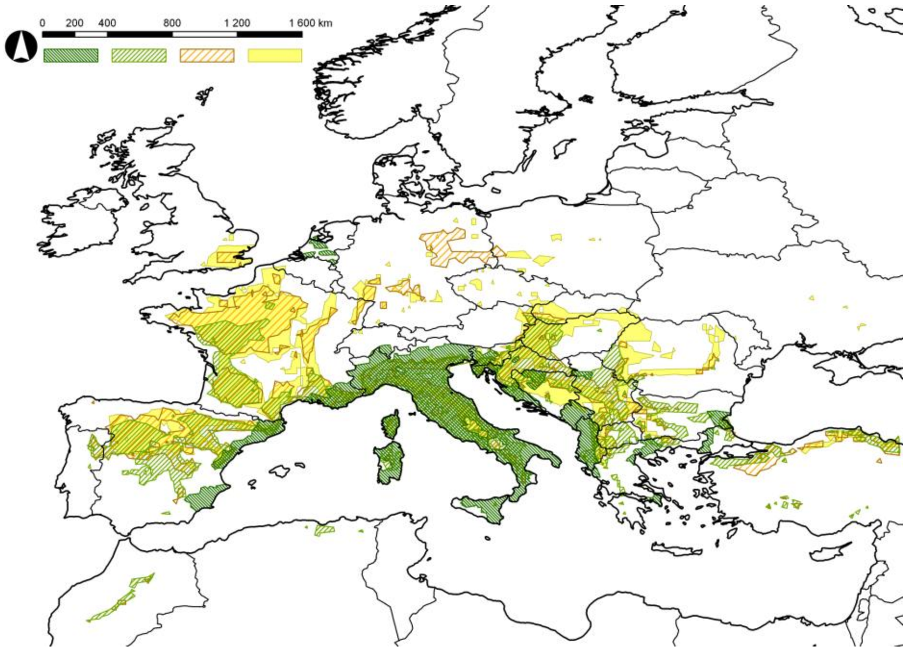

Fig. 13. The recent (2012) distribution of *A. albopictus* mosquito (dark green according to the VBORNET database), the potential distribution area for the reference period (1961–1990, light green), and the projected future distribution for the periods of 2011–2040 (orange) and 2041–2070 (yellow).

4. Discussion

The comparison of the recent and predicted future distributions of a vector and a vector-borne diseases, at first aspect, may seem to be problematic, but the recent geographical range of WNF is cannot be explained without the climate factors. The most important determinants of the spatial range of *Ae. albopictus* are climate factors according to our model.

The recent distribution of WNF suggests that climate, topographically the run of the rivers, floods, the migrating routes of birds, and the annual ontogeny of *Culex* mosquitoes together determine the occurrence of the disease.

The annual features of the epidemics suggest brief exposures in multiple focuses. In contrast to the Lyme disease occurrence in Hungary (Lyme disease is also an emerging vector-borne disease) WNF did not show constant occurrence pattern in 2008 and 2010–2012. It may explained by the fact, that in the case of Lyme disease, the parasite permanently persists in the local tick and host animal populations, while it is plausible, that birds recurring from Africa and the Mediterranean wetlands are re-introduce WNV into Hungary every year. It also explains the very low incidence of WNF in Hungary.

Our findings showed that floods have an important influence on annual WNF case number. There are differences between the major rivers, since over the larger Danube less WNF cases were observed in every year than between the smaller, but more natural rivers as Tisza and its tributaries, which have backwaters, wreaths and high amplitude water level changes. The high water level fluctuation can play an important role to create the appropriate conditions for mosquito populations (as this phenomenon is known in the case of *Anopheles darlingi* Anopheles Meigen (1818) malaria mosquitoe; *Rozendaal*, 1992) and consequently for the presence of WNF. The water level of Tisza as a characteristic representative of the rivers of the Carpathian Basin and the annual WNF case number simultaneously changed between 2007 and 2011. We studied separately the year of 2012 and we found, that the contradiction was apparent, since most of the cases occurred in Transdanubia and not in the Tisza valley thanks to the extraordinary low water level of the Tisza in this year.

According to *Epstein* (2010), the epidemic of WNF is ecologically similar to that of the St. Louis encephalitis, since these two vector-borne diseases are connected to long, hot, and dry (continental) summers with occasionally wet summers, when the case number generally is the highest. Extreme summer rainfalls are favored by WNF, and the increasing amount of extreme meteorological events are one of the consequences of climate change (*Fay et al*., 2008; *Meehl et al*., 2000). It may explain the observations, since the year of 2010 in Hungary was unusually wet; the total annual rainfall was two times higher than the average of the last 100 years, the 25% of the cases occurred in this year. Naturally, we cannot make conclusions based on the observations of a single year.

In the case of the *Aedes* mosquito, the connection between the climate and the geographical distribution is the clearest. The main determinants of the European distribution of *Ae. albopictus* are climatic conditions, mainly the mean temperature in July, the minimum temperature in January, and the low precipitation of the summer months (Mediterranean summers). Climatically the geographical occurrence of WNF is partly determined by the warm ambient temperature of July and August with wet summers. According to the VBORNET (2012) database, the recent occurrence of WNF in Europe is mainly similar to the migration route of white stork from the east sub-saharan Africa (e.g., Uganda, by via Sinai) to central and eastern Europe. Although climatic factors alone cannot explain the observed occurrence of West Nile virus, they indicate that dry and warm summers, and heavy rainfalls can enhance the population density of *Culex* mosquitoes (*Reeves et al*., 1994; *Reiter*, 2001). According to *Sellers* and *Maarouf* (1990), warm winds may carry infected mosquitoes from the dry riverbanks to northern areas. The above described extreme weather events are specific to continental climate conditions, where the disease recently occurred.

The seasonality of WNF is regular as far as it can be judged from the low case number of the last decade, it starts in late July, has a peak from August to mid-September and declines, when the weekly mean ambient temperature drops below 13–14 °C. Climate change may cause a shift in the WNF season elongating the hottest period of summer and enhancing the warmer period of the autumn season. This seasonality may correspond to the spring early summer migration of birds (*Jourdain et al.*, 2007), in the sense that time needs to ensure a sufficient number of mosquito contaminate with the virus for the chance of human transmission.

In contrast to, e.g., *Culex pipiens* or *Culex modestus, Ae. albopictus* mosquito prefers the more balanced conditions and milder winters of subtropical coasts of the Mediterranean basin. Higher summer precipitation seems to be a major limiting factor in the model for *Ae. albopictus*, which is in accordance with the study of *Alto* and *Juliano* (2001) who found that Asian tiger mosquito populations occurring in warmer regions are likely to produce more adults as long as water bodies (e.g., containers, little ponds) do not dry completely. We found, that *Ae. albopictus* does not prefer the wetter climate of the oceanic areas of Western Europe, which also matches with *Alto* and *Juliano* (2001) who found that the populations of the mosquito in cooler regions produce less amount of adults with the variability of precipitation. In the case of *Aedes* mosquito, wetlands and floodplains do not seem to be primary determinants of the distribution. Our model findings are highly in accordance with the findings of *Fischer et al*. (2011) who projected the future expansion of *Ae.albopictus* mosquito to the end of the 2060’s to France, the western part of the Carpathian Basin.

The major benefit of our model is that the observed temperature requirement of the WNF peak season in Hungary is similar to the modeled temperature needs (T_{mean} of the summer months and September is more than 20 °C). Since 3 days to two weeks latency is plausible (CDC), the mosquito bites may occur at higher weekly mean temperatures.

5. Conclusions

Our study indicates that in creating a climate envelope model for a vector-borne disease or a vector, the primary concern is to consider the behavior, and the requirements of every elements of the vectorial chain. Climate can be the main determinant of the distribution, but in other cases climate itself is not sufficient to explain the observed distribution or occurrence. The predicted future warmer and dryer summer seasonal climate of the Carpathian Basin is likely to extend the northern distribution of *Ae. albopictus* and may modify the seasonality of West Nile fever. Floods has a very important role in modifying the mosquito abundance rivers which have a major water running as the river Tisza and have more or less preserved floodplains offering better conditions for mosquitos than the highly regulated rivers. Recently it is plausible, that birds re-introduce WNF into Hungary from year to year.

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