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THE RISK OF VECTOR-BORNE ZOONOTIC DISEASE TRANSMISSION IN THE CONTEXT OF GLOBAL WARMING

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Abstract. *The incidence of mosquito-borne diseases varies geographically, with the transmission period potentially changing in response to the constant interaction between pathogens, hosts, vectors, and the environment with climate warming. In Iași County and the Great Brăila Island, 9 mosquito species have been identified: Aedes albopictus, Culex pipiens, Aedes caspius, Culex modestus, Aedes vexans, Anopheles maculipennis, Anopheles hyrcanus, Coquillettidia richardii, Culiseta anulata. Based on the temperatures developed in Romania, the risk of vector-borne diseases transmission was calculated: West Nile, malaria, Saint Louis encephalitis virus, Zika, Usutu, Sindbis, equine encephalitis virus. The results show that all these diseases can be transmitted in Romania during certain periods of the year, in the context of the presence of the mosquito vector*.

Keywords: *vector-borne diseases, climate warming*

Introduction

Pathogens transmitted by vectors affect both animals and humans, zoonotic vector diseases being much more difficult to manage once established in a certain territory, especially when the reservoir in nature is represented by wild animals (Tolle, M.A., 2009). The effects of global warming and its impact on vector-borne diseases such as malaria and dengue fever, for example, have been the subject of research by scientists. In the latest decades, new health risks have emerged in Europe, particularly with the recent emergence of vector-borne diseases such as Chikungunya, West Nile Virus, dengue and Crimean-Congo hemorrhagic fever (P.J. Hotez 2016, O. Olesen 2017). Of the approximately 593 viral diseases identified in animals, an average of 29% are transmitted exclusively by vectors (Johnson et al., 2015). The epidemiology of vector-borne diseases is influenced by climate and climate change, which alter the disease cycle (Randolph, 2009). Vector-borne diseases cause socioeconomic losses worldwide. Tick-borne diseases (TTBDs), especially anaplasmosis, babesiosis, trypanosomiasis and theileriosis have a major effect on the productive performance of animals, especially cattle (Rajput et al., 2006). Every year there are more than 700,000 deaths caused by a series of diseases such as dengue, malaria, Japanese encephalitis, human African trypanosomiasis, Chagas disease, schistosomiasis, leishmaniasis, yellow fever and onchocerciasis. During the last century, the global climate was greatly affected by anthropic activity, and in the coming decades, climate changes are expected, which can have a dramatic impact on ecosystems, especially as a result of changes in the abundance and distribution of mosquito species worldwide. Being ectothermic organisms, mosquito vectors are affected by climate change, since many characteristics of their physiology, life cycle, behavior and vector competence are temperature dependent (Cator et al.,

2020). In addition, temperature can modify the biological cycle of the pathogen inside the vector, but also in humans and other vertebrate hosts (Paz, 2015). Temperature is the key factor limiting the establishment of invasive species in temperate regions, determining their distribution and seasonal abundance (Brugueras et al., 2020, Giulia Giunti et al., 2023). Climate warming is confirmed on the Eurasian continent (G. Giunti et al., 2023, Romanello et al., 2021). Outbreaks of emerging mosquito-borne diseases have been reported more frequently in southern Europe since 2000 (Brugueras et al., 2020). Anthropic changes such as urbanization, climate change and environmental pollution play a very important role in modifying vector distribution (Wilke et al., 2021; Ferraguti et al., 2022).
Our research regarding the risk of vector-borne disease transmission due to global warming concludes that, for both diseases transmitted by mosquitoes and those transmitted by ticks, it is necessary in Romania to introduce a monitoring program for vectors and vector-borne diseases. Therefore, with regard to diseases transmitted by mosquitoes, our research focused on assessing the risk of transmitting some vector borne diseases in the context of global warming.

Material and methods

1. Climate change

Using a mathematical model that we have implemented, which is based on the construction of a Lagrange polynomial interpolation function we realized a temperature curve starting from 1961 till 2020, indicating a constant increase of temperatures by 1.3°C, compared with t the malaria eradication period.
Doing an extrapolation of the evolution of temperatures in 2050 we can see a slight increase of temperatures by an average of 24°C in 2050 (in the summer months), which may ensure a favorable climate for the development of culicids, the optimal temperatures for development being between 23-25°C.

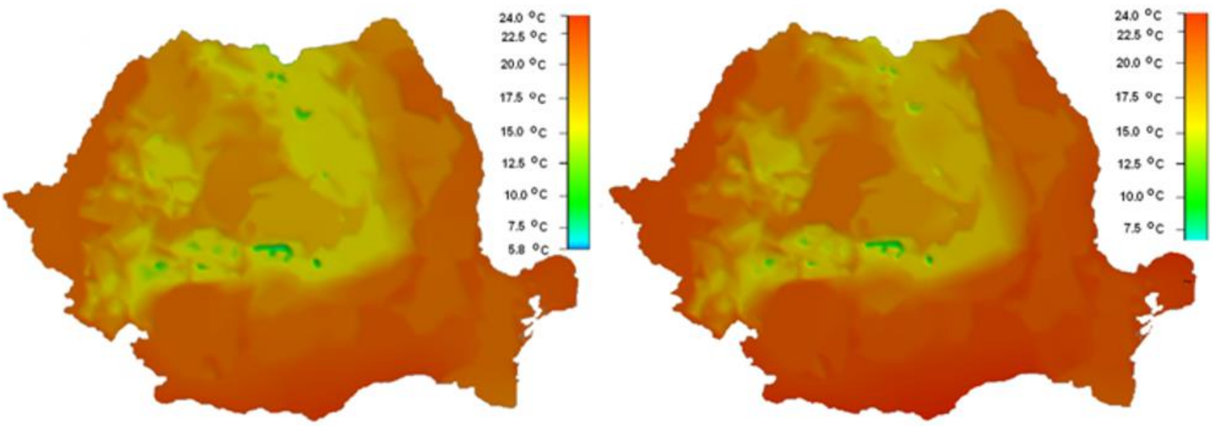

Fig. 1. (left – temperatures for year 2020; right – temperatures for 2050) The extrapolation of temperatures for the year 2050 shows an increase of temperatures by 0.8°C, results which coincide with the forecast formulated by prestigious Institutes, such as NIES, CSIRO, HCCPR, MPIM and NCAR, which shows an increase of temperatures by 0.8 – 1.7°C for the year 2050

The complex model of projections (CMIP5) (Kunkel et al., 2013) considers the impact of anthropogenic activities on the greenhouse gases which affect the atmosphere, changing the natural radiative forcing of Earth. Radiative forcing and the history of climatic parameters are used as input into physical models which provide an output able to assess the impacts, adaptation and vulnerability to climatic changes. We simplified the implementation of the climatic model assuming that the CMIP5 is valid. We therefore kept the same initial conditions and only adapted the model to the radiative forcing and temperature at regional conditions. As it is a mathematical model, we used the pattern scaling technique, in which the estimated temperature is determined as a product between a scalar term and response pattern of temperature. In our regional circulation approach, the annual average temperature at time t was used as scalar, and the response pattern of temperature was related to radiative forcing. This term was computed based on a linear least squares regression for temperature sequences. This approach was used to estimate the possible daily temperature in 2100 in all regions of this study. The results obtained were applied to determine the most probable values for the bioclimatic indices already described.

2.The risk of transmission of vector-borne diseases

Using this mathematical model, we have calculated the risk of vector-borne disease transmission in Romania, as well as the development of vector populations throughout the year.

Usutu and Sindbis viruses

Anti-Usutu and Sindbis antibodies have been found in patients in Iași County, but the viruses were not identified inside mosquitoes, so we cannot precisely determine the period of transmission in Romania. According to specialized literature, the virus remains viable for a sufficient period of time inside the mosquito, during the summer months. The Sindbis virus is transmitted at a temperature of 23.2°C. Therefore, the months with favorable thermal values are April, May, June, July, August, September. The Usutu virus is transmitted at a temperature of 28°C, with June, July, and August being the months with potential for transmission. The species Culex pipiens and Culex modestus are vectors for the Usutu virus, Rift Valley fever virus, Sindbis virus, Tahyna virus, and Batai virus. Both Culex pipiens pipiens and Culex molestus transmit dirofilariasis, being vectors for Dirofilaria immitis and Dirofilaria repens. Avian malaria caused by Plasmodium relictum and Plasmodium vaughani is transmitted by these mosquito species. Additionally, it has been established that the Culex modestus species transmits the Lednice virus, and Culex pipiens is a vector for the Rabensberg virus.

Malaria

In Europe, malaria is transmitted by mosquitoes from the *Anopheles maculipennis* complex, species also identified in Iași County. *Plasmodium vivax* completes its life cycle in 21 days at temperatures of 4-5.5°C; *Plasmodium falciparum* completes its life cycle in 15 days at 25°C. For malaria transmission, different temperature values and the number of days during which transmission is possible vary: for *Plasmodium falciparum* - at 28°C, 9-10 days, and at 20°C, 22 days. *Plasmodium vivax* - at 28°C, 8-10 days, and at 20°C, 16 days. *Plasmodium malariae* - at 28°C, 14 days, and at 20°C, 30-35 days. *Plasmodium ovale* - at 28°C, 12-14 days. Therefore, the months during which the disease can spread are April, May, June, July, August, September, October.

Dirofilariasis

Dirofilariasis is a disease caused by the nematodes *Dirofilaria immitis* and *Dirofilaria repens*, parasites transmitted by mosquitoes from the genera *Aedes, Culex, Anopheles*, *Mansonia*. The temperature necessary for the development of *Dirofilaria immitis* larvae is 27°C, within a period of 10-14 days. The months during which dirofilariasis can be transmitted are May, June, July, August, September.

Rift Valley fever

Rift Valley fever is caused by a *Phlebovirus* from the *Bunyaviridae* family. It causes mortality in newborn ruminants, especially in sheep and goats, and abortion in pregnant animals. Regarding Rift Valley fever, the optimal temperature for transmission is 26°C. Thus, the disease can be transmitted in the months of May, June, July, August, and September.

Zika virus

The *Zika* virus is a flavivirus transmitted by mosquitoes from the genus *Aedes,* first identified in monkeys in Uganda in 1947. When pregnant women are infected, the newborn will present microcephaly and other congenital anomalies. There have also been records of abortion and premature birth. In adults and older children, the pathogen has caused the emergence of Guillain-Barré syndrome, neuropathy, and myelitis. The Zika virus is transmitted at a temperature of 29°C. Therefore, it can be spread in the months of June, July, and August.

Saint Louis encephalitis virus

Most people are asymptomatic. The incubation period ranges between 4 and 14 days. Clinical signs include fever, headaches, dizziness, nausea, and weakness, which can worsen within a week. The virus requires a temperature of 30°C for transmission. Therefore, it can be spread in the months of June, July, and August.

Eastern Equine Encephalitis

Eastern and Western Equine Encephalitis are caused by alphaviruses from the Togaviridae family. Elderly individuals and infants can develop encephalitis. Clinical signs include fever, headaches, neck stiffness, vomiting or weakness, disorientation, irritability, seizures, and coma. Eastern Equine Encephalitis is transmitted at a temperature of 22.7°C, while Western Equine Encephalitis is transmitted at a temperature of 23°C. The months during which these pathogens are transmitted are May, June, July, August, September, October.

Dengue fever

We followed the evolution of temperatures in Romania until 2100, calculating also the risk of dengue virus transmission. In the Danube Delta and East of Romanian Plain, from the point of view of temperatures, the populations of Ae. albopictus can develop from March to November, but the dengue virus can replicate in the salivary glands and can produce the disease during the feeding of the female mosquito, only in the months of July, August and September, especially in August. But until the year 2100 in HS, the risk period of virus transmission increases to 5 months a year, from June to October. These results provide important details to better guide surveillance and control programs of Ae. albopictus population; also having a significant importance for public health as a reference point for predicting the occurrence of dengue fever in Romania.

West Nile virus

Distribution of WNV cases in Romania differed among different regions, with 56%being recorded in the East of the Romanian Plain (also known as Wallachian Plain), 14% in the Oltenia Plain and an average of 9% in the narrow area of the Danube Valley. The Danube Valley is a favorable environment for the development of Culex mosquito populations because the optimal temperature-humidity conditions are met. Compared to the area and the number of inhabitants, the percentage of

West Nile cases was highest in the Wallachian Plain. Average temperatures recorded at meteorological stations in Romania from 1961–2020 increased constantly after 1991. Record temperatures were registered in the decade 2011–2020. In the low regions of Romania, from a thermal point of view, mosquito hatching and development are possible until the first week of November and the development of the WNV inside the mosquito can occur until October. The simulations under the conditions of climate change for the year 2100 show that in the coming decades, these periods may be extended by another month, which favors the development of mosquito populations transmitting the virus in all low-lying regions of Romania throughout the year.

3. Identification of mosquito species in the southeast and northeast of Romania

In the Great Brăila Island area, on the Măcini-Danube Old Arm, and in the northeast part of Romania in the city of Iași, with the purpose of identifying mosquito species and to see if the *Aedes albopictus* species is showing tendencies of spreading to the northern part of the country; traps were placed in areas considered favorable for vector development (trees with hollows, water accumulations, abundant vegetation). CDC Light Traps with dry ice as attractant and manual aspirators for collecting females directly from the human host were used. The traps were set during the night from 20:00-08:00 for species in the *Anopheles* and *Culex* genera, and from morning till dusk for the Aedes albopictus species. The female exhibits anthropophilic behavior and bites at dawn and dusk, between 15:00 and 19:00. Mosquitoes were identified based on morphological characteristics, using the identification keys presented by Becker et al., 2010, and the interactive keys from the MosKeyTool program (Pasteur Institute, France).

At the collection points in Iași, the following species were identified: *Aedes vexans, Anopheles maculipennis complex, Ochlerotatus caspius, Culex pipiens, Culex modestus, Ochlerotatus sticticus, Coquillettidia richardii, Anopheles pseudopictus.* Based on data provided by the National Meteorological Administration, average temperatures recorded throughout 2023 were calculated, establishing the density of mosquito populations identified throughout the year, as well as the risk of vector-borne disease transmission based on the vectorial capacity of each species. For the Culex pipiens species (a competent vector for many arboviruses), according to specialized literature, eggs hatch after just one day at 30°C, three days at 20°C, ten days at 10°C, and below 7°C, embryonic development cannot be completed. Larvae develop into adults in a few weeks, depending on the temperature (6-7 days at 30°C, 21-24 days at 15°C) (Becker N, et al, 2010). The evolution of average temperatures in Romania for the year 2022 indicates that the Culex pipiens species is active, potentially producing several generations a year starting in March and continuing until the first half of November. Thus, analyzing the graphs, we can estimate 8 generations per year for this native species. Adults of *Culex modestus* have peak activity from the beginning of July until the end of September. Being a resilient species according to temperature trends, in 2022, the *Culex modestus* species could begin its activity from the start of April, continuing until the end of October. According to the temperature evolution in 2022, species of the *Anopheles maculipennis* complex can be active from January until November, but they represent an important vector of malaria during periods with average temperatures of 19-25°C for at least two weeks.

Table 1. Bioclimatic and temperature indices for 1991-2020 and estimates for 2100

Region	Index	January	February	March	April	May	June	July	August	September	October	November	December	Annual
Moldavian Plateau	T_{month} (average 1991-2020)	-1.9	0.2	5.1	11.4	16.8	20.8	22.6	22.0	16.7	10.6	5.3	0.0	10.8
	T_{month} (estimation 2100 - LS)	-0.5	1.2	4.8	11.7	17.3	21.4	23.0	22.2	16.6	11.4	4.8	0.2	11.2
	T_{month} (estimation 2100 - HS)	1.7	3.4	7.0	13.9	19.5	23.6	25.2	24.4	18.8	13.6	7.0	2.4	13.4
	MPI_m (1991-2020)	0	0	0	9	27	30	31	31	23	5	0	0	156
	PII_m (1991-2020)	0	0	0	0	0	0	1	2	2	0	0	0	4
	PII_m (estimation 2100 - LS)	0	0	0	0	0	0	1	3	3	0	0	0	6
	PII_m (estimation 2100 - HS)	0	0	0	0	0	1	5	9	7	0	0	0	23
East of Romanian Plain	T_{month} (average 1991-2020)	-1.2	1.4	6.4	12.1	17.5	21.7	23.9	23.6	18.1	11.8	6.3	0.7	11.9
	T_{month} (estimation 2100 - LS)	0.1	1.9	6.2	12.7	18.2	22.7	24.4	23.7	18.1	12.5	5.9	0.8	12.3
	T_{month} (estimation 2100 - HS)	2.3	4.1	8.4	14.9	20.4	24.9	26.6	25.9	20.3	14.7	8.1	3.0	14.5
	MPI_m (1991-2020)	0	0	0	12	29	30	31	31	27	9	1	0	169
	PII_m (1991-2020)	0	0	0	0	0	0	1	4	3	0	0	0	8
	PII_m (estimation 2100 - LS)	0	0	0	0	0	0	3	7	5	0	0	0	15
	PII_m (estimation 2100 - HS)	0	0	0	0	0	1	8	15	12	1	0	0	37
Oltenia Plain	T_{month} (average 1991-2020)	-0.2	2.1	6.9	12.6	17.4	21.4	23.5	23.3	18.0	12.0	6.5	1.2	12.1
	T_{month} (estimation 2100 - LS)	0.8	2.8	6.8	12.8	18.0	22.3	24.0	23.7	18.1	12.8	6.3	1.5	12.5
	T_{month} (estimation 2100 - HS)	3.0	5.0	9.0	15.0	20.2	24.5	26.2	25.9	20.3	15.0	8.5	3.7	14.7
	MPI_m (1991-2020)	0	0	1	13	28	30	31	31	27	10	1	0	171
	PII_m (1991-2020)	0	0	0	0	0	0	1	4	4	0	0	0	9
	PII_m (estimation 2100 - LS)	0	0	0	0	0	0	2	5	6	0	0	0	13
	PII_m (estimation 2100 - HS)	0	0	0	0	0	1	7	13	12	1	0	0	34

	T_{month} (average 1991-2020)	-0.2	2.0	6.7	12.4	17.8	22.1	24.3	23.8	18.4	12.3	7.0	1.6	12.4
	T_{month} (estimation 2100 - LS)	0.9	2.6	6.3	12.8	18.4	22.7	24.6	23.9	18.4	13.0	6.6	1.7	12.7
	T_{month} (estimation 2100 - HS)	3.1	4.8	8.5	15.0	20.6	24.9	26.8	26.1	20.6	15.2	8.8	3.9	14.9
Danube Valley	MPI_m (1991-2020)	0	0	1	12	29	30	31	31	28	10	1	0	173
	PII_m (1991-2020)	0	0	0	0	0	0	2	4	4	0	0	0	10
	PII_m (estimation 2100 - LS)	0	0	0	0	0	0	2	6	6	0	0	0	14
	PII_m (estimation 2100 - HS)	0	0	0	0	0	1	8	16	12	1	0	0	38
	T_{month} (average 1991-2020)	-1.7	0.6	5.2	11.1	15.8	19.5	21.2	20.9	15.7	10.3	5.1	-0.1	10.3
	T_{month} (estimation 2100 - LS)	-0.8	0.6	4.9	11.0	16.1	19.8	21.3	21.1	15.8	10.8	5.1	0.1	10.5
	T_{month} (estimation 2100 - HS)	1.4	2.8	7.1	13.2	18.3	22.0	23.5	23.3	18.0	13.0	7.3	2.3	12.7
Transylvania	MPI_m (1991-2020)	0	0	0	9	23	30	31	30	21	5	0	0	149
	PII_m (1991-2020)	0	0	0	0	0	0	0	1	1	0	0	0	2
	PII_m (estimation 2100 - LS)	0	0	0	0	0	0	0	1	2	0	0	0	3
	PII_m (estimation 2100 - HS)	0	0	0	0	0	0	2	4	4	0	0	0	11

The mathematical calculations used by us show that, if drastic measures are taken to limit greenhouse gas emissions, temperatures will increase by 0.4°C in the region of Moldova by 2100 (Low Scenario - LS) and by 2.6°C (High Scenario - HS) if these specific actions are not taken, or not taken efficiently. Dengue virus will replicate within the vector, establishing a transmission season from July to September under LS conditions, and from June to September with an increase in the number of days under HS conditions, compared to the current period, when until 2020 the longest interval favorable for virus replication was recorded five times.

For the Romanian Plain, temperatures are expected to increase by 0.4°C in LS and by 2.6°C in HS until 2100, but with an increase in the period of virus replication from June to October in HS, and from May to September in LS. The same temperature change can also be observed in the Oltenia region, with a prolongation of the risk of virus transmission in October in HS. In the Danube Delta, an increase in temperatures by 2100 in LS by 0.3°C and in HS by 2.5°C is observed, and the risk of Dengue virus transmission increases to 38 favorable periods from June to October in HS. In Transylvania, the temperature will increase by 0.2°C in LS and by 2.4°C in HS by 2100, with a 6-fold risk of virus transmission from July to September (Table1). Regarding the favorable periods for the development of *Ae. albopictus* populations, it can be observed that in the Danube Delta Valley and in Oltenia from March to November there was at least one favorable period for the development of a complete cycle from egg to adult.

Conclusions

Global warming and increased intercontinental travel pose a risk of disease emergence in Romania. Increasing temperatures thus widen the geographical range of the vector, increase the number of blood samples, increase reproduction rates and shorten the incubation period of the pathogen inside the vector.

For a disease to become emergent in a given territory, 3 factors must coexist: a. the existence of the pathogen in nature; b. the existence of the vector in nature; c. the existence of favourable climatic factors to the development of the vector and the pathogen within it.

We have realized an extrapolation of the temperature evolution for the year 2100, using the mathematical model, suggesting the progression of some favourable conditions for the development of the mosquito's vector and of the pathogen inside of it. The extrapolation of temperatures for the year 2100 shows an increase of temperatures by 2,6°C in HS and 0,4°C in LS. So in Romania we have the mosquitoes vector in continuous spread, we have annual cases of vector borne disease imported and we have favorable climatic conditions. The risk of vector borne diseases epidemics in Romania is continuously increasing.

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