

Anticipating the locations in Europe of high-risk areas for West Nile virus outbreaks in 2021

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Abstract

West Nile virus infections in humans are continuously increasing, and the virus has spread considerably in Europe over the past decade. The incidence of the disease was unusually high between 2018 and 2020. The resulting model identifies the West Nile virus outbreak-prone areas during 2021, even in regions where the virus has not yet been discovered. It is remarkable that in Central Europe, new favourable areas are emerging, where early actions could lessen the impact of the disease.

KEYWORDS

Europe, infectious disease, outbreak, prediction, West Nile virus, Zoonoses

1 | INTRODUCTION

West Nile virus (WNV) is an emergent and widely distributed pathogen of particular importance because it has serious economic and health consequences. Its recent spread in both the New World and the Old World seems to be related to the emergence of a strain with greater virulence in birds, humans and equids (Gubler, 2007). Given the increasing significance of WNV for European public health, understanding environmental contributions to the occurrence of the disease and detecting high-risk areas are key to taking preventive measures and better comprehending the consequences of climate warming in the spread of the disease. The study of zoonotic diseases has recently been approached from a biogeographic perspective, that is pathogeography (Murray et al., 2018). The aim of pathogeography is to understand the processes that drive the distribution patterns of diseases, applying biogeography to the research and management of human infectious diseases and promoting collaboration and interdisciplinary research among biogeographers, veterinary and medical

practitioners and ecologists. In this study, we aimed at the detection of new favourable areas in Europe for the occurrence of WNV disease during the current transmission season in 2021, considering the outbreaks that occurred during 2020.

2 | MATERIALS AND METHODS

We compiled all areas in Europe where WNV outbreaks occurred during the transmission season of 2020 (Spain, Italy, the Netherlands, Germany, Hungary, Romania, Bulgaria and Greece), which yielded a total of 308 human cases (Figure 1), including 36 deaths (European Centre for Disease Prevention & Control, 2020). The study area was divided into administrative districts called NUTS (Nomenclature of Territorial Units for Statistics) level 3, which divide the economic territory of the European Union (European Commission, 2003). A set of environmental variables was used to build an environmental favourability model to detect the effect of environmental conditions that

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favour WNV occurrence and the distribution of cases throughout the study area in 2020 (Table 1).

The risk model was elaborated following several steps. First, through univariate logistic regression we assessed the environmental power of each environmental variable. Multicollinearity among the environmental variables was controlled by calculating pairwise Spearman correlation coefficients. If two variables, belonging to the same factor (Table 1), were correlated by more than 0.8, the least explanatory one was deleted. The false discovery rate was controlled to avoid an increase in type I errors due to the number of variables used in the analysis (Benjamini & Hochberg, 1995). Finally, we performed a multivariate forward-stepwise logistic regression in which a variable was added to the null model if the resulting regression was most significantly improved by the new variable. The result was a probability value (P) of WNV outbreak in each NUTS according to its environmental characteristics. The P value of each NUTS was transformed into a favourability value (F) using the favourability function (Real et al., 2006).

$$F = \frac{\frac{P}{1-P}}{\left(\frac{n1}{n0}\right) + \left(\frac{P}{1-P}\right)}$$

with $n1$ being the number of NUTS with reported WNV cases, and $n0$ the number of NUTS with no virus outbreak reported. The result was an F value (ranging from 0 to 1). This favourability model shows how the local probability of WNV outbreak differs from that expected by chance in Europe and thus identifies those localities with environmental conditions that favour outbreak occurrence. A detailed description of the methodological processes is available in the work of García-Carrasco et al. (2021).

3 | RESULTS

Four variables were significantly associated with the areas of high environmental favourability for WNV outbreaks during the 2020

Impacts

- West Nile virus is an emergent disease that has recently caused sporadic outbreaks in humans, horses and birds in Europe, increasing human morbidity and mortality.
- Since 2018, the disease has been spreading north, where we have detected areas favourable for the occurrence of outbreaks.
- Results from this study have direct and short-term utility. Data on outbreaks in humans could be predicted a year in advance, reducing the impact of human outbreaks of West Nile virus during the transmission season in Europe.

transmission season in Europe. Areas close to watercourses, with rice paddies and a high density of chicken farms, were the zones with the highest risk of occurrence of WNV cases in humans (see Figure 1). Furthermore, the risk increased in those areas with high mean annual temperatures.

Southern Europe hosts the most favourable areas for WNV outbreaks, in particular the south of the Iberian Peninsula, Italy, the Balkan Peninsula and the countries included in the Danube River Basin (Figure 1). Although so far, Italy has experienced WNV cases only in the Po River Basin, we have identified high-risk areas throughout the country. The same could be said in the Balkan countries; only Greece suffered the disease in 2020, but Albania, Bulgaria, North Macedonia, Montenegro and Serbia have been identified as highly favourable for WNV. In Spain, the south region is most at risk of suffering outbreaks, and not just in the marshes of the Guadalquivir River, where WNV infection in humans was reported in 2020. New potential infection areas were identified in northern Belgium and in the south of the Netherlands. Only one human WNV case was detected in the Netherlands during 2020, although WNV has also been detected in one migrant bird, the common whitethroat (*Sylvia communis*), and mosquitoes (Krol &

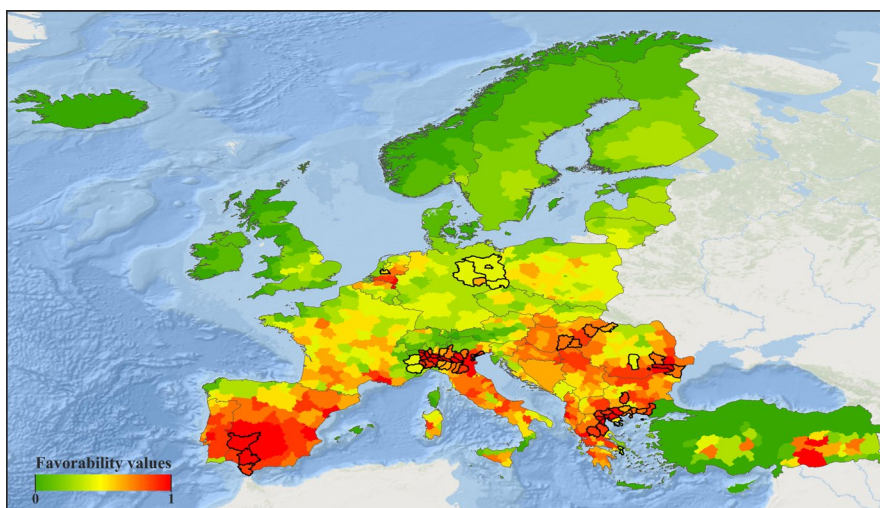


FIGURE 1 Environmental risk model of West Nile virus in Europe. Red tones indicate regions with high favourability for virus outbreaks to occur. Areas with black outlines are those that presented WNV cases in 2020

TABLE 1 Explanatory variables used in the WNV 2017 case models in Europe

Type	Subtype	Abbreviation	Name		
Humans	Human concentration	dens_pob	Population density ^a		
		distcenpob	Distance to population centre ^b		
	Livestock	fao_chicken	Chicken density ^c		
		fao_duck	Farmed duck density ^c		
		fao_horse	Horse density ^c		
		fao_pig	Pig density ^c		
	Infrastructure	dist_road	Distance to roads ^d		
		cor_urban		Continuous urban fabric ^e	
				Discontinuous urban fabric ^e	
				Industrial or commercial units ^e	
			Construction sites ^e		
			Road and rail networks and associated land ^e		
		Agriculture	cor_grUrban	Green urban areas ^e	
			cor_dry		Non-irrigated arable land ^e
					Vineyards ^e
					Olive groves ^e
				Annual crops associated with permanent crops ^e	
	cor_rice		Rice fields ^e		
	cor_irrig			Permanently irrigated land ^e	
				Fruit trees and berry plantations ^e	
	Pastures ^e				
	cor_het_cult	Complex cultivation patterns ^e			
	cor_agr_veg	Land principally occupied by agriculture with significant areas of natural vegetation ^e			
Non-humans	Ecosystem	cor_agrfores	Agro-forestry areas ^e		
		cor_broadleaf	Broad-leaved forest ^e		
		cor_conif	Coniferous forest ^e		
		cor_mixforest	Mixed forest ^e		
		cor_grass	Natural grasslands ^e		
		cor_moor	Moors and heathland ^e		
		cor_scler	Sclerophyllous vegetation ^e		
		cor_trans	Transitional woodland-shrub ^e		
		cor_spars_veg	Sparsely vegetated areas ^e		
		cor_in_marsh	Inland marshes ^e		
		cor_peat	Peat bogs ^e		
		Hydrographic	cor_sal_marsh	Salt marshes ^e	
			cor_saline	Salines ^e	
	cor_tidalFlat		Intertidal flats ^e		
	cor_river		Water courses ^e		
	cor_wat_body		Water bodies ^e		
	cor_coast_lag		Coastal lagoons ^e		
	cor_estuar		Estuaries ^e		
	Topographic	dist_rio	Distance to rivers ^f		
		alt	Altitude ^g		
slope		Slope ^h			

(Continues)

TABLE 1 (Continued)

Type	Subtype	Abbreviation	Name
	Climatic	Bio1	Annual mean temperature ⁱ
		Bio5	Max temperature of warmest month ⁱ
		Bio6	Min temperature of coldest month ⁱ
		Bio7	Temperature annual range (Bio5-Bio6) ⁱ
		Bio12	Annual precipitation ⁱ
		Bio15	Precipitation seasonality (coefficient of variation) ⁱ

^aLandScanTM 2008 High Resolution Global Population Data Set (copyrighted by UT-Battelle, LLC, operator of Oak Ridge National Laboratory), excluding any areas less than 2-km far from urban areas (as delimited by the MODIS 500 -m Map of Global Urban Extent for 2001–2002 (Schneider et al. 2009; 2010).

^bAdministrative Centres & Populated Places shapefile at the Relational World Database II (RWDB2) updated in 2000 (<http://www.fao.org/geoneetwork>).

^cGlobal FAO 2010 livestock (<http://www.fao.org/livestock-systems/en/>).

^dVector Map Level 0 at the Digital Chart of the World (DCW, <http://worldmap.harvard.edu>), updated in 2002.

^eCorine Land Cover 2018 (<https://land.copernicus.eu/pan-european/corine-land-cover/clc2018>).

^fGlobal Drainage Basin Database GDBD. Released Version 1.0: May 29, 2007 (http://www.cger.nies.go.jp/db/gdbd/gdbd_index_e.html).

^gGTOPO30 (US Geological Survey 1996).

^hElaborated from DEM (Digital Elevation Model) using the altitude variable (GTOPO30; US Geological Survey 1996), using the Geographic Information System ArcGIS Desktop 10.3.

ⁱChelsa (<http://chelsa-climate.org>).

Mastrigt, 2020). It is also remarkable that other surrounding areas also present favourable environmental conditions for WNV cases to occur. Additionally, we have detected new areas with intermediate favourability for WNV occurrence in Central Europe, mostly in Poland and eastern Germany, where some cases occurred during 2020.

4 | DISCUSSION

Even though chickens are not competent species to reinfect biting mosquitoes with WNV, chicken farms constitute an ideal setting for WNV vector proliferation (Sowilem et al., 2019). A high density of chicken farms means a high quantity of blood meal available for ornithophilic mosquitoes, the same that transmit the virus from bird to bird, and eventually from bird to humans. Watercourses and paddy fields provide ideal breeding areas for mosquitoes and attract migratory birds (Hardy et al., 1983; Liang et al., 2015), which may carry the virus from other areas. Environmental temperature is widely known as an important driver of WNV transmission by increasing the replication rate of the virus (Hardy et al., 1983), shortening the gonotrophic cycle of mosquitoes and favouring the early transmission of the virus (Ciota et al., 2014; Hartley et al., 2012). As temperature is involved in the distribution of human WNV cases in Europe, change in environmental temperatures might influence the spread of the virus. Climate change could produce changes in the distribution of vectors at higher altitudes, but also at higher latitudes (Semenza & Suk, 2018). This could explain the cases in Central Europe, as an increase in temperature is occurring mainly in Central and Northern Europe (Andriamifidy et al., 2019; I.P.C.C., 2014).

As the spread of the disease has been proven to be facilitated within the same watershed (García-Carrasco et al., 2021), our model suggests that special attention should be paid to the basins of the rivers Danube, Po, Elba and Aegean and the southern watersheds of the Iberian Peninsula. In these highly favourable areas, the disease is more likely to occur, manifest earlier and appear more intensely during the next epidemic season (García-Carrasco et al., 2021).

Prevention plays a more important role than ever in the case of infectious diseases. As survival in mosquitoes might facilitate the annual recurrence of the virus at the same sites where outbreaks occurred the previous year (Rappole et al., 2000), our modelling approach should be regularly updated to continue predicting the risk in subsequent years. Following the incidence of WNV in Southern Spain during the summer of 2020, health authorities carried out fumigation plans in sensitive areas as well as campaigns to increase citizen awareness to reduce mosquito bites (using mosquito nets, avoiding being outside at sunrise and sunset, etc.). Other countries, such as Italy, implemented veterinary and entomological surveillance in those regions that have commonly recorded the disease. These types of preventive measures should also be incorporated in those regions with high favourability for human WNV cases where the disease has not yet been reported. Although mosquito populations and disease dynamics may vary across scales smaller than NUTS, our model facilitates the detection and location of those areas newly exposed to WNV outbreaks. Once we have identified the variables that most contribute to explaining WNV cases in Europe, we can recommend the development of prevention methods in specific areas within the NUTS that meet certain environmental conditions favouring the development of the disease, such as villages and cities in proximity of rivers, with the presence of rice croplands and a high density of chicken farms.

Although the first known cases of WNV in Europe were located in a few southern and eastern countries, the number of affected countries is increasing, including Spain in the south and reaching areas in higher latitudes as the Netherlands in Central Europe. This type of risk model may contribute to identifying the disease-prone areas on a yearly basis and could be regularly updated to better anticipate WNV outbreaks. Early actions in risky areas could lessen the impact of the disease in the following transmission season, reducing the number of affected people. Our study highlights the usefulness of pathogeography as an emergent discipline for the study of infectious diseases in constantly changing societies and environments.

CONFLICT OF INTEREST

The authors declare that they have no competing interests.

ETHICAL APPROVAL

Not applicable.

DATA AVAILABILITY STATEMENT

Data sharing not applicable to this article as no datasets were generated or analysed during the current study.

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