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Research Paper

Assessing Seasonal Risks for the Introduction and Mosquito-borne Spread of Zika Virus in Europe

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ABSTRACT

The explosive Zika virus epidemic in the Americas is amplifying spread of this emerging pathogen into previously unaffected regions of the world, including Europe (Gulland, 2016), where local populations are immunologically naïve. As summertime approaches in the northern hemisphere, *Aedes* mosquitoes in Europe may find suitable climatic conditions to acquire and subsequently transmit Zika virus from viremic travellers to local populations. While *Aedes albopictus* has proven to be a vector for the transmission of dengue and chikungunya viruses in Europe (Delisle et al., 2015; ECDC, n.d.) there is growing experimental and ecological evidence to suggest that it may also be competent for Zika virus(Chouin-Carneiro et al., 2016; Grard et al., 2014; Li et al., 2012; Wong et al., 2013). Here we analyze and overlay the monthly flows of airline travellers arriving into European cities from Zika affected areas across the Americas, the predicted monthly estimates of the basic reproduction number of Zika virus in areas where *Aedes* mosquito populations reside in Europe (*Aedes aegypti* in Madeira, Portugal and *Ae. albopictus* in continental Europe), and human populations living within areas where mosquito-borne transmission of Zika virus may be possible. We highlight specific geographic areas and timing of risk for Zika virus introduction and possible spread within Europe to inform the efficient use of human disease surveillance, vector surveillance and control, and public education resources.

1. Introduction

On May 17th, 2015, the Program for Monitoring Emerging Diseases (ProMED-mail) published a report confirming locally acquired cases of Zika virus (ZIKV) in several northeastern Brazilian states, marking the first time this virus is known to have spread within the Americas (Promed, 2015). Eight months later, on February 1st, 2016 the World Health Organization declared the ZIKV epidemic in the Americas a Public Health Emergency of International Concern, in part due to an emerging association with congenital birth anomalies such as microcephaly (Calvet et al., 2016; Mlakar et al., 2016; Rodrigues, 2016) and Guillain-Barré syndrome (Cao-Lormeau et al., 2016). After the virus' introduction into Brazil, the epidemic has swiftly spread across Latin America and the Caribbean (Faria et al., 2016; Petersen et al., 2016a). Potential reasons for this rapid spread include the presence of immunologically naïve populations and an abundance of *Aedes* mosquitoes (Kraemer et al., 2015) within a conducive environment.

As the epidemic expands in scale and geographic range, a growing number of travellers are exporting ZIKV to other regions of the world, including Europe, where *Aedes* vectors are known to be present (Maria et al., 2016; Zammarchi et al., 2015; http://ecdc.europa.eu/en/healthtopics/vectors/vector-maps/Pages/VBORNET_maps.aspx, n.d.). In Europe, *Aedes aegypti* is known to exist on the island of Madeira, Portugal (http://ecdc.europa.eu/en/healthtopics/vectors/vector-maps/

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Pages/VBORNET_maps.aspx, n.d.) and in parts of Georgia and south-western Russia, whereas *Aedes albopictus* is established along much of the Mediterranean coast (http://ecdc.europa.eu/en/healthtopics/vectors/vector-maps/Pages/VBORNET_maps.aspx, n.d.). While virus importation events could trigger epidemics in distant geographies where competent *Aedes* mosquito vectors exist, this risk has to date, been mitigated by winter temperatures in the northern hemisphere.

Given the growing experimental and ecological evidence to suggest that *Ae. albopictus* may be a competent vector for ZIKV (Chouin-Carneiro et al., 2016; Grard et al., 2014; Li et al., 2012; Wong et al., 2013), health officials must plan for the possibility of locally acquired ZIKV infections in parts of Europe. The imminent arrival of summer in the northern hemisphere, when *Aedes* mosquito populations will peak and viral replication within these vectors will be most efficient, could lead to autochthonous transmission, not unlike the recent localized and transient European epidemics of dengue and chikungunya (Angelini et al., 2007; Wilder-Smith et al., 2014).

To assist public health decision-making, we (i) modeled the risks of ZIKV importation into Europe via airline travellers departing areas in the Americas where ZIKV activity has been confirmed or where suitable conditions exist for its transmission year round (Bogoch et al., 2016), (ii) used a temperature driven vectorial capacity model to quantify the potential for European *Aedes* mosquitoes to support autochthonous transmission of ZIKV, assuming that *Ae. albopictus* is a competent vector, and (iii) quantified the size of populations living in European areas where mosquito-borne transmission of ZIKV may be possible at the height of summer.

2. Materials & Methods

2.1. Overview

We developed a mathematical model that outputs basic reproduction numbers (R_0) for ZIKV transmission with biological anchoring in *Aedes* mosquito vectorial capacity and validation against surveillance data from the current ZIKV outbreak in Latin America and the Caribbean. We applied this vectorial capacity model to estimate R_0 potential for ZIKV in Europe this spring to autumn, while superimposing data on airline travellers arriving from areas in the Americas where ZIKV is active, as well as populations living in areas of Europe where mosquito-borne transmission of ZIKV is possible. Finally we discuss model assumptions and limitations in our approach.

2.2. Model Development

R_0 is used to characterize the epidemic potential of a pathogen. It represents the expected number of new infections generated by one infectious individual within a fully susceptible population. In the context of a mosquito-borne illness, R_0 is a function of vectorial capacity (VC), and the period of viremia in humans (T_h) (Anderson and R, 1991), given mathematically by: $R_0 = VC \times T_h$. Transmission increases when R_0 exceeds 1 (i.e. potential for an epidemic), and diminishes when R_0 is less than 1. VC in turn is a function of vector competence (inherent ability of the vector to transmit a particular pathogen), vector lifespan, and the extrinsic incubation period (Lambrechts et al., 2011). Since *Aedes* mosquitoes are ectotherms, VC is highly dependent upon mean

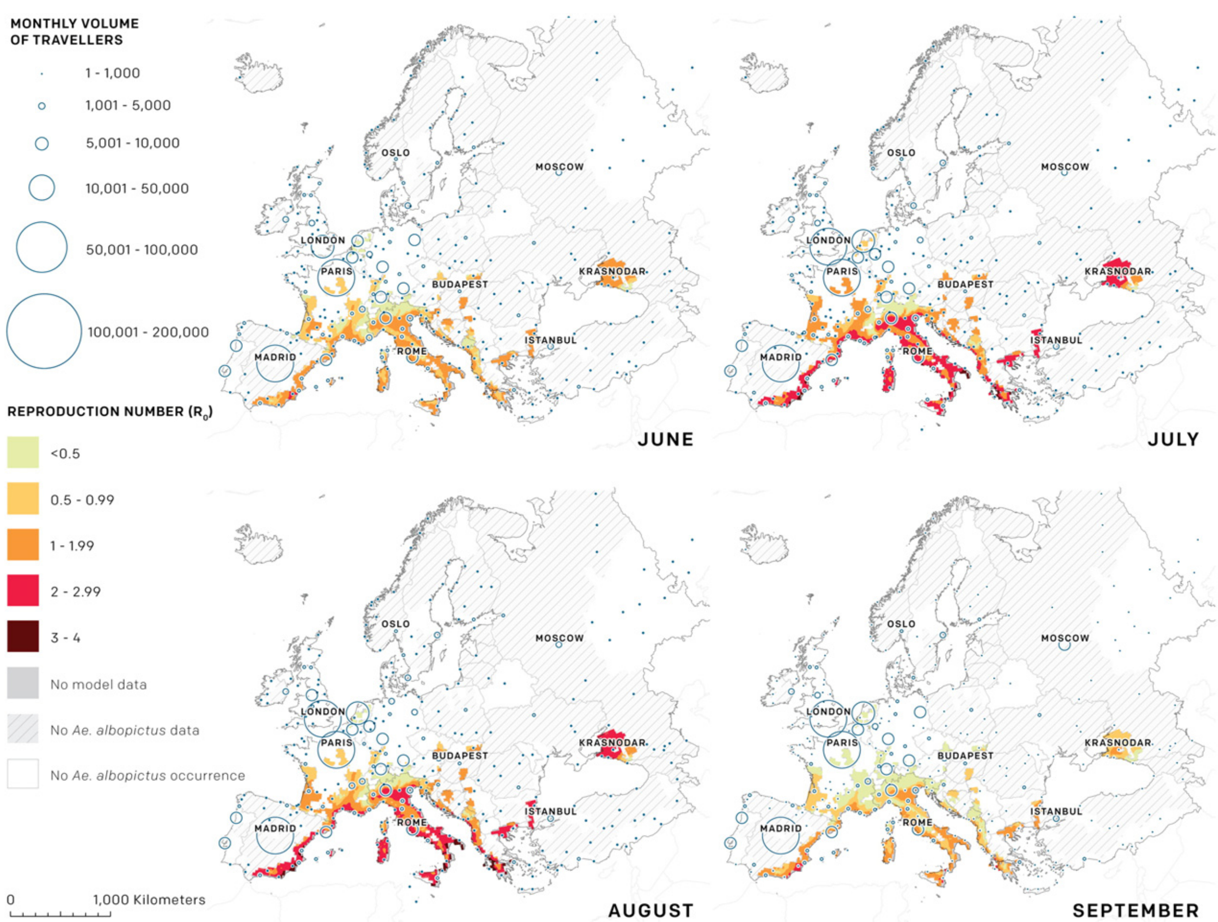

Fig. 1. Monthly stratified maps (June–Sept) of the potential basic reproduction number (R_0) of Zika virus in Europe via *Aedes albopictus* overlaid with monthly estimates of airline travellers arriving from areas with potential for year-round Zika transmission in the Americas.