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SHORT REPORT
Potential exposure to Zika virus for foreign tourists during the 2016 Carnival and Olympic Games in Rio de Janeiro, Brazil

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The recent outbreak of Zika virus in Brazil has triggered a wave of anxiety that is felt throughout the world. The anxiety is fuelled by the mounting evidence that Zika virus is associated with an unprecedented upsurge of microcephaly and other congenital malformations, thereby putting pregnant women and their offspring at risk. Furthermore, statistical associations of Zika virus infections with Guillain–Barré syndrome underpin the additional serious threat of this new emerging Zika virus to everyone [1]. Therefore, it is very important for travellers to Zika virus-affected areas or countries to estimate the risk for acquiring a Zika virus infection. Such risk estimates have particular importance for tourists during the Carnival events in February 2016 or those planning to attend the Olympic Games in August 2016, with both events occurring in Rio de Janeiro. However, for risk estimations one would need to know the true burden of Zika virus disease and quantify the force of infection in Rio de Janeiro over the time periods of the Carnival and the Olympic Games. At this stage, however, such data are still preliminary, the reasons of which are many: Zika virus is a flavivirus, therefore serologically based diagnostic tests are highly cross-reactive with dengue viruses. Furthermore, the clinical picture of both diseases is sufficiently similar to make misdiagnosis frequent. Brazil has the highest dengue burden in the world, and hence Zika virus infections remain initially undetected in the overwhelming number of dengue infections [2]. However, Zika virus and dengue virus infections have one thing in common that may help to indirectly estimate the risk of Zika virus infections: both are transmitted by the same *Aedes* mosquitoes, and hence the potential exposure to Zika and dengue viruses can be calculated through mathematical modelling based on *Aedes* mosquito bites. In other words, the primary research question is the calculation of the risk of a tourist receiving a bite from an *Aedes* mosquito in Rio. Some preliminary estimation of the risk of acquiring Zika virus infection are presented.

We set out to calculate the risk of foreign tourists being bitten by an *Aedes aegyptii* mosquito, the predominant species in Rio, during the carnival week (7–13 February) and the Olympic Games (5–20 August) 2016 in Rio de Janeiro.

For this, we considered the force of infection during the dengue outbreak of 2008, a year with a very large dengue outbreak due to a serotype that was relatively new. From the official notification system, SINAM, we calculated the force of infection for dengue in Rio for 2008. Figure 1 shows the actual number of dengue cases and the total number of mosquitoes distributed by week in 2008, as explained below.

To estimate the number of mosquitoes, we applied a mathematical model previously developed for describing dengue transmission dynamics. The total number

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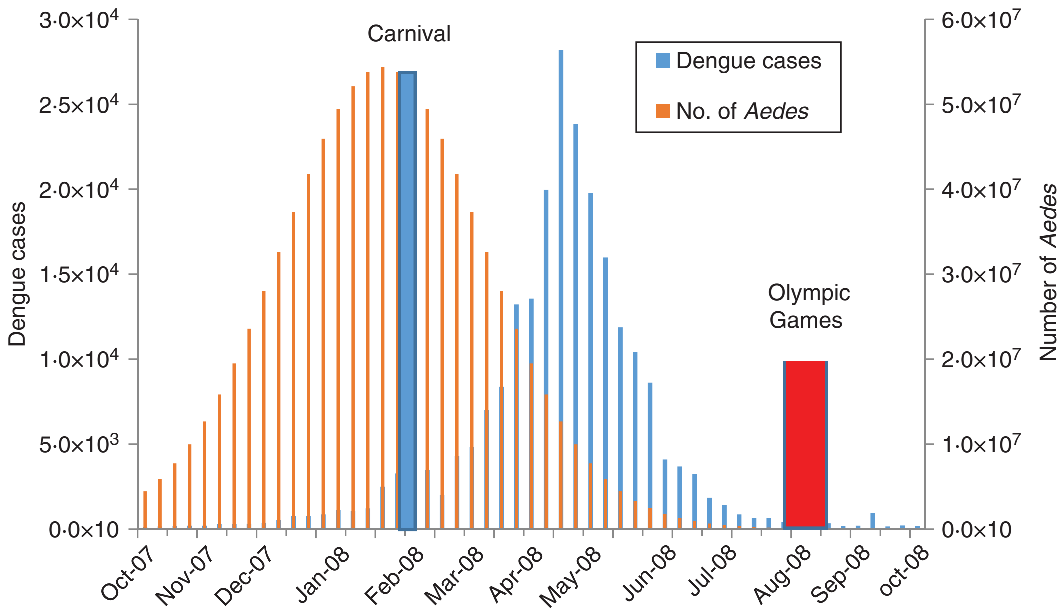

Fig. 1. Total number of *Aedes* mosquitoes and dengue cases in Rio distributed along the epidemiological weeks in 2008. The Carnival week and the Olympic Games weeks are shown.

of *A. aegypti* population, was denoted $N_M(t)$ in references [3] and [4]. Using this approach, we were able to show what should be the total mosquito population size that when used in the model would reproduce the dengue outbreak observed in Rio in 2008. One of the most important parameters related to dengue transmission is the *Aedes* biting rate, denoted a. The value assumed for this parameter was based on published data [4, 5]. Hence, with the size of the mosquito population, $N_M(t)$ and the biting rate, a, we calculated the so-called 'man-biting rate', denoted MBR(t), i.e. the average number of bites from *Aedes* mosquitoes each individual received per time unit, in Rio in 2008. From the MBR, it is possible to calculate the probability of a tourist receiving at least one bite from an *Aedes* mosquito during the 1 week of Carnival and the 3 weeks of Olympics Games, that occur in different weather seasons in Rio. Thus we assume that 2016 will have the same contact rate with *Aedes* mosquitoes as in 2008 and that those tourists will have the same biting rate of the local inhabitants of Rio.

The probability of being bitten, $P_{\text{bitten}}(t)$, is calculated as follows [3, 4]:

$$p_{\text{bitten}}(t) = 1 - \exp\left(-\int_{t_1}^{t_2} \text{MBR}(t)\text{d}t\right). \qquad (1)$$

The resultant probability of being bitten would therefore be approximately 99% per individual traveller spending 1 week in Rio de Janeiro during the Carnival, but only 3·5% during the 3-week period of the Olympics Games.

The risk of acquiring Zika virus during Carnival week and the 3 weeks of the Olympic Games could be estimated from the virus's force of infection $\lambda(t)$. This, in turn, depends on the time-dependent incidence data, of which we have only preliminary results. However, as a first approximation, we calculated $\lambda(t)$ from the 27 146 reported number of Zika cases notified in 2015 in Brazil [6]. Therefore, the individual risk of acquiring the infection from Zika-infected mosquitoes, Risk(t), is given by

$$\text{Risk}(t) = 1 - \exp\left(-\int_{t_1}^{t_2} \lambda(t)\text{d}t\right). \qquad (2)$$

The steps for this estimation are:

Fit a continuous function

$$\lambda(t) = c_1 \exp\left[-\frac{(t-c_2)^2}{c_3}\right]F(t),$$

where c_1 is a scale parameter that determines the maximum incidence, c_2 is the time at which the maximum incidence is reached, c_3 represents the width of the time-dependent incidence function and $F(t)$ is an *ad hoc* function introduced to both improve the model fit to the data and to set the initial time of infection

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c_5. This function has the 'logistic' form:

$$F(t) = \frac{1}{1 + \exp(-c_4(t - c_5))},$$

where c_4 determines the rate at which the incidence increases.

We apply this force of infection to the simple model (S_H and I_H represent susceptible and infected humans, respectively, and μ, γ and α are human natural mortality, recovery from infection, and disease-induced mortality rates, respectively).

$$\frac{dS_H}{dt} = -\lambda(t)S_H - \mu S_H,$$

$$\frac{dI_H}{dt} = \lambda(t)S_H - (\mu + \gamma + \alpha)I_H,$$

such that the parameters $c_i, i = 1, \ldots, 5$, which reproduce the incidence data (reported cases) are found.

We apply the function $\lambda(t)$ to equation (2) to calculate the risk.

The resulting risk for Zika infection for tourists visiting Rio during the Carnival week festivities in February and the 3 weeks of the Olympic Games in August are 3·6/100 000 and 1·8/1 000 000 tourists, respectively. If, by contrast, the total number of Zika infections in Brazil in 2015 was 1·5 million cases (anecdotal information, as yet unconfirmed), then the respective risks would be 1·3/1000 and 3·2/100 000 tourists for the Carnival and Olympic Games periods, respectively. These are, however, very preliminary calculations and are dependent on the total confirmed cases of Zika in 2015.

The Zika outbreak in the Americas is considered a public health emergency by the WHO [7] due to its possible association to microcephaly [8]. There are many uncertainties about the actual size of the epidemic and its dynamics, which hampers the estimation of the relevant risks associated with Zika virus infection.

We emphasize that the aim of this report is to present an estimation of the maximum risk that a tourist to Rio has of being bitten by an *Aedes* mosquito.

The consequent potential exposure to Zika is based on very preliminary data on the actual size of the epidemics and is, therefore, based on some strong assumptions like the tourists' susceptibility to both the bites and the infection being the same as for local inhabitants. In the face of so many unknowns about Zika epidemics, the modelling approach presented here is intended to fill in the blanks for empirical facts about transmission under investigation. As soon as more reliable data is available on the intensity of Zika transmission, the inputs to the model (and its outputs) will serve to produce better decision on the risk of infection for travellers intending to visit Brazil.

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DECLARATION OF INTEREST

None.

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