ORIGINAL ARTICLES

A Quantitative Risk Assessment of West Nile Virus Introduction into Barbados

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ABSTRACT

Objective*: To present a quantitative risk assessment of West Nile (WNV) virus introduction into Barbados, West Indies.*

Design and Methods*: Three possible modes were considered: a) WNV infected mosquitoes via air transport, by city of departure, b) WNV infected mosquitoes via marine transport and c) viraemic migratory birds. We estimated the number of WNV infected migratory birds as the product of the proportion of migratory birds infected and the number of migratory birds entering Barbados in three taxonomic groups. We further estimated the number of days these birds would be infectious as:*

$$\frac{1}{n}\sum_{i=1}^{n}\sum_{j=i}^{n}\left(\int_{5}^{15.3} I_m(v_i)N(v_i,\sigma)dv + \int_{15.3}^{\infty} N(v_i,\sigma)dv\right).$$

We then estimated the number (#) of infectious mosquito-days for mosquitoes entering Barbados via air transport as:

 # infected mosquitoes = (total flights per week/city) x (duration of WNV season) x (number of Culex *mosquitoes aboard each flight) x (*Culex *mosquito WNV infection prevalence) x (vector competence index) x (days infectious)*

The number of infected mosquitoes entering Barbados via marine transport was estimated using a similar expression as for air transport, except that the number of airplanes and mosquitoes/airplane were substituted with the # of sea containers during a 22-week mosquito season and # of mosquitoes/container.

Results: *Migratory birds (~69–101 infected birds/year) were associated with the highest introductory risk followed by mode (a) (~2 infected mosquitoes/year) and mode (b) (0.004 infected mosquitoes/year)*

Conclusions: *Migratory birds and mosquitoes via air are imminent threats for virus introduction. Impending co-circulation of West Nile virus and four strains of dengue virus may present new challenges for public health.*

Una Evaluación del Riesgo Cuantitativo de la Introducción del Virus del Nilo Occidental en Barbados

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RESUMEN

Objetivo: *Presentar una valoración del riesgo cuantitativa de la introducción del Virus del Nilo Occidental (VNO) en Barbados, West Indies.*

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Métodos y diseño: *Se consideraron tres posibles modos: a) mosquitos infectados con el VNO vía transporte aéreo, por ciudad de salida, b) mosquitos infectados con el VNO vía transporte marítimo, y c) aves migratorias virémicas.* *Calculamos el número de aves migratorias infectadas con el VNO como el producto de la proporción de aves migratorias infectadas por el número de aves migratorias que entran a Barbados en tres grupos taxonómicos. Luego calculamos el número de días en que estas aves serían infecciosas, de la forma siguiente:*

$$\frac{1}{n}\sum_{i=1}^{n}\sum_{j=i}^{n}\left(\int_{5}^{15.3} I_m(v_i)N(v_i,\sigma)dv + \int_{15.3}^{\infty} N(v_i,\sigma)dv\right).$$

Calculamos entonces el número de días-mosquito infeccioso para los mosquitos que entran en Barbados mediante transporte aéreo, como sigue: # mosquitos infectados = (vuelos totales por semana/ciudad) x (duración de la estación del VNO) x (número de mosquitos Culex a bordo de cada vuelo) x (prevalencia de infección con VNO por mosquito Culex) *x (índice de competencia del vector) x (días infecciosos). El número de mosquitos infectados que entraron a Barbados por vía del transporte marítimo fue calculado usando una fórmula similar a la usada en relación con el transporte aéreo, excepto que el número de aeroplanos y mosquitos/ aeroplanos fueron sustituidos con el # de contenedores marítimos durante una temporada de mosquitos de 22 semanas y el # de mosquitos/contenedor.*

Resultados: *Las aves migratorias ~ (69–101 aves infectadas/años) estuvieron asociadas con el riesgo de introducción más alto seguido del modo (a) (~2 mosquitos infectados/año), y finalmente el modo (b) (0.004 mosquitos infectados/año).*

Conclusiones: *Las aves migratorias y los mosquitos por vía aérea representan una amenaza inminente de introducción de virus. La co-circulación inminente del Virus del Nilo Occidental y cuatro cepas de virus de dengue pueden presentar nuevos desafíos a la salud pública.*

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INTRODUCTION

West Nile virus (WNV) is a small spherical enveloped flavivirus of the Japanese encephalitis (JE) serocomplex primarily transmitted between birds and ornithophilic *Culex* species (1). It first appeared in North America in 1999 and now significantly impacts human and wildlife health, causing hundreds of thousands of avian mortalities and more than 27 000 human cases with > 1055 deaths (2, 3). West Nile virus has since been spread southwards to the Caribbean perhaps through WNV-infected migratory birds (4).

Objective

The objective of this study was to determine the risk of WNV introduction into Barbados by different pathways, to identify possible mitigation strategies, areas for surveillance and control, and the most probable season of introduction. Barbados is the most eastern of the Caribbean islands located at 13º 10N, 59º 32W with a population size of 270 000. A high level of flaviviral immunity (89%) is present amongst the Barbadian population (5) due to circulation of four dengue virus sero-types (DENV 1–4) (5). This pre-existing immunity could be either beneficial by attenuating disease due to presence of cross-protective antibodies (6) or detrimental if immune enhancement exacerbates disease symptoms (7). If the latter occurs, WNV entry into Barbados could present challenges to human health officials.

METHODS

West Nile virus entry into Barbados was examined via a) migratory birds b) mosquitoes via air and c) mosquitoes via marine transport. The number of WNV infected migratory birds was estimated as the product of the proportion of infected migratory birds (15/12,000 based on a study in the Atlantic and Mississippi flyways (R. McLean, personal communication) (8) and the number of migratory birds entering Barbados in three taxonomic groups (shorebirds, ducks, passerines). We further estimated the number of days these birds would be infectious as:

$$\frac{1}{n}\sum_{i=1}^{n}\sum_{j=i}^{n}\left(\int_{5}^{15.3} I_m(v_i)N(v_i,\sigma)dv + \int_{15.3}^{\infty} N(v_i,\sigma)dv\right)$$

where the terms in parentheses represent the integral of the probability of distribution of a bird's viraemia on day *i*; v_i, assuming a normal distribution and variance, σ^2; multiplied by the probability of a bite leading to a disseminated infection in a mosquito, I_m, (given the host's viraemia) and summed over the viraemic period *n* (in days) for that species, using killdeer for shorebirds, mallard for ducks and an average of ten passerine species (9).

We estimated the number (#) of infectious mosquito-days for mosquitoes entering Barbados via air transport as: # infected mosquitoes = (total flights per week/city) x (duration of WNV season) x (number # of *Culex* mosquitoes aboard each flight) x (*Culex* mosquito WNV infection prevalence) x (vector competence index) x (days infectious) Direct flights to Barbados that originated from North American cities or countries with WNV activity were examined and the investigation estimated the duration of the peak WNV season to be 22 weeks (10). The number of live mosquitoes aboard each airplane (1.55) was based on two studies of airplanes landing in Japan and Australia, which were primarily *Culex pipiens* and *Culex quinquefasciatus* (11). The WNV mosquito infection prevalence was based on estimates from Florida (for Florida, Jamaica and Puerto Rico); (12) and New York (for other US cities and Canada) (10). It was assumed that 22% of the WNV-infected *Culex* mosquitoes would transmit WNV with a bite (13). It was also estimated conservatively that mosquitoes would be WNV-infectious for approximately 10–20 days, based on an average lifespan of 30–60 days for *Culex quinquefasciatus* in the laboratory and 7–14 days needed for viral development within the mosquito (13,14). The number of infected mosquitoes entering Barbados via marine transport was estimated using a similar expression as for air transport, except that we substituted the number of airplanes and mosquitoes/airplane with the number of sea containers (which are primarily from Miami, FL) during a 22-week mosquito season and number of mosquitoes per container (0.0005) (15).

RESULTS

Migratory birds and mosquitoes on airplanes represented significant risks for the introduction of WNV to Barbados (Table 1). Although the number of viraemic birds migrating to Barbados each year was quite high (69–101/yr), the relatively low infectiousness and duration of viraemia for these birds reduced the risk from this pathway. In contrast, the number of WNV-infectious mosquitoes that are introduced to Barbados by air each year is relatively low (2.2/yr) but the lifelong infectiousness of mosquitoes increases the relative risk of this pathways.

Table 2 shows the relative contribution of mosquitoes on airplanes from different North American and Caribbean cities. Outbound flights from Miami, Puerto Rico and New York airports carried the greatest risk of introducing WNV infected mosquitoes to Barbados due to the large number of flights each week.

Table 2: Estimated number of WNV-infectious mosquitoes introduced to Barbados via direct flights from North American cities assuming a 22-week WNV season.

Airport Location	# of flights/ week	WNV prevalence	# WNV-infectious mosquitoes/year
Toronto, ON	8		0.20
New York, NY	19		0.48
Newark, NJ	1	0.0034	0.03
Philadelphia, PA	8		0.20
Washington, DC			0.08
Miami, FL	15		0.54
Puerto Rico	13	0.0048	0.47
Jamaica	7		0.25
Total	**74**		**2.25**

Table 1: Estimated numbers of WNV-infectious mosquito vectors and avian hosts introduced into Barbados annually.

Mode	# hosts or vectors	Fraction WNV infected	# WNV infectious	# WNV-infectious days
Mosquitoes by air	825 x 1.55	0.22 x (0.0034 or 0.0048; Table 2)	2.25	23–45
Mosquitoes by boat	16751[a] x 22/52 x 0 .0005	0.0048	0.004	0.04–0.07
Migratory birds	55,500–81,000	15/12 000	69–101	23.7–34.3
Shorebirds	~50–70,000[b]	15/12 000	62.5–87.5	22–31
Ducks	~5–10,000[b]	15/12 000	6.3–12.5	1.7–3.4
Passerines	~500–1000	15/12 000	0.6–1.3	0.2–0.4

[a] – Container Release Book, Customs and Excise Department, pers. comm.
[b] – K. Watson, (personal communication)

DISCUSSION

The study found that WNV-infected mosquitoes present on airplanes represent a substantial risk for WNV introduction to Barbados. This mirrors results from a similar analysis of WNV introduction into Hawaii (16). The use of insecticide to spraying cargo holds of airplanes prior to departure from areas of WNV activity could be an effective measure to reduce the threat of WNV introduction by this pathway (11).

This analysis also suggested that viraemic migratory birds represent a substantial risk supporting previous assertions that migratory birds may have introduced WNV into other Caribbean islands (4). If WNV is introduced to Barbados by this pathway it would arrive in late September and most likely near wetland areas (*eg* Graeme Hall Nature Sanctuary) where a large proportion of migrating birds arrive. The arrival of WNV in Barbados could likely result in human infections given the presence of competent ornithophilic and mammophilic vectors such as *Culex quinquefasciatus* and *Aedes albopictus* (17).

The co-circulation of WNV and all four dengue serotypes make the impact of WNV entry at Barbados quite unpredictable. It is unclear whether DENV infection would delimit or enhance WNV infection amongst mosquito vector and human host populations. Regardless, if WNV entry is to be prevented efforts must begin as soon as possible in order for them to be effective against a continuous rapid spread of WNV through the Caribbean.

The type of risk assessment we have performed enables health officials to determine how a disease is likely to be introduced, when during the year it is likely to be introduced, and in some cases, what actions may be taken to reduce the likelihood of its introduction (18). This should enable better allocation of surveillance efforts and more effective planning for human and veterinary cases. Overall, this study aids in facilitating planning efforts of health officials in Barbados and serves as a model for other pathogens and systems worldwide.

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