



Establishment of *Aedes aegypti* (L.) in mountainous regions in Mexico: Increasing number of population at risk of mosquito-borne disease and future climate conditions

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ABSTRACT

The study was conducted in the central region of Veracruz Mexico, in the metropolitan area of Xalapa. It is a mountainous area where *Aedes aegypti* (L.) is not currently endemic. An entomological survey was done along an elevation gradient using the *Ae. aegypti* occurrences at different life cycle stages. Seven sites were sampled and a total of 24 mosquito species were recorded: 9 species were found in urban areas, 18 in non-urban areas with remnant vegetation, and 3 occurred in both environments. *Ae. aegypti* was found only in the urban areas, usually below 1200 m a.s.l., but in this study was recorded for the first time at 1420 m a.s.l. These occurrences, together with additional distribution data in the state of Veracruz were used to develop species distribution models using Maxlike software in R to identify the current projected suitable areas for the establishment of this vector and the human populations that might be affected by dengue transmission at higher elevations. Its emergence in previously unsuitable places appears to be driven by both habitat destruction and biodiversity loss associated with biotic homogenization. A border study using data from the edges of the vector's distribution might allow sensitive monitoring to detect any changes in this mosquito's distribution pattern, and any changes in the anthropic drivers or climate that could increase transmission risk.

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1. Introduction

Dengue is considered a re-emergent disease of high priority since it affects the people who live in the cities located in the hottest areas around the world. Dengue is the fastest spreading vector-borne disease. Even though the WHO (2009, 2016) <http://goo.gl/Q1W1UI> reports that every year about 50 million people become infected with one of the five serotypes of *Flavivirus dengue* (dengue virus or DVIR), Bhatt et al. (2013) stated there are 390 million dengue infections per year, of which 96 million manifest apparently any level of disease severity. This is more than three times the dengue burden than that estimated by the World Health

Organization¹ in 2009. The increasing number of cases is associated with human demography and environmental transformation (Farrar et al., 2007; Normile, 2013). Recent results show that human mobility could be the main driving force in the dynamics of the epidemic caused by this vector (Barmak et al., 2016). Human migration and urbanization that is both intensive and irregular are reported as the most important variables related to the expansion of dengue in the Americas (IPCC, 2014). Also, changes in the distribution of its vector, independently of the virus' distribution, have been found to correlate with increases in air temperature and relative humidity at both regional and global scales (Hopp and Foley, 2001, 2003; Patz et al., 2005; Hurtado-Díaz et al., 2007; Johansson et al., 2009; WHO, 2009; Barbazan et al., 2010; Chaves et al., 2012). The average

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¹ World Health Organization. Dengue: Guidelines for Diagnosis, Treatment, Prevention and Control. WHO/HTM/NTD/DEN/2009.1 (WHO, 2009 World Health Organization, 2009).

worldwide distribution is below 1200 m a.s.l. However, *Ae. aegypti* has been recorded at elevations around 2400 m a.s.l. in Africa, and in March 2016 the Director of the Health Department in La Paz, Bolivia (SEDES) confirmed the presence of *Ae. aegypti* at 2600 m a.s.l. in the cities of Cochabamba and Tarija (Ruiz-López et al., 2016).

In Mexico, *Ae. aegypti* generally occurs below an elevation of 1200 m a.s.l. (SSA, 2007), but in 1987 *Ae. aegypti* was first found in Mexico at an elevation greater than 1200 m a.s.l., and there are now records for this mosquito at elevations as high as 1630 m a.s.l. in the state of Morelos (Ibáñez-Bernal, 1987). In 1988 the first high elevation dengue outbreak was documented for the city of Taxco, Guerrero at 1735 m a.s.l. (Herrera-Basto et al., 1992). In 2011, specimens were reported at an elevation of 1850 m a.s.l. in the city of Querétaro (SSA, 2012) and in 2012 three of its larvae were collected at 2100 m a.s.l. in the city of Puebla, Puebla (Lozano-Fuentes et al., 2012). During nationwide sampling in 2015, only Tlaxcala (2230 m a.s.l.) and Mexico City (2240 m a.s.l.) did not report any cases of dengue linked to *Ae. aegypti* records (Cruz-Martínez, 2016). The return or emergence of infectious diseases appears to be driven by habitat destruction and biodiversity loss associated with biotic homogenization that together increase the incidence and distribution of infectious diseases (Pongsiri et al., 2009; Myers et al., 2013), allowing them to establish as urban vector-borne diseases.

In Mexico, the state of Veracruz is particularly important (Escobar-Mesa and Gómez-Dantés, 2003) because of all the states in the country it often reports the highest number of dengue cases (Fig. 1). During 2004, the state of Veracruz had the most cases of dengue fever and the most cases of dengue hemorrhagic fever reported nationwide to that point, a situation that occurred again in 2015 with the highest number of hospitalizations due to dengue fever and dengue hemorrhagic fever ever recorded. In 2007, Veracruz recorded the highest number of dengue disease-related deaths (Gómez-Dantés et al., 2014). The state of Veracruz is situated on the coastal slope of the Sierra Madre Oriental mountain range, and nearly its entire population lives below 1400 m a.s.l. This elevation range lies well within the current band associated with *Ae. aegypti*. The upper vertical distribution limit of this mosquito species in Veracruz is considered to be 1200 m a.s.l. (Cervantes-Ocampo, 2014).

Over the last decade, it has been thought that the city of Xalapa, capital of the state of Veracruz has the potential for dengue outbreaks for two reasons: it has a high percentage of people moving constantly between the coast and the city, and it is close to areas where dengue is endemic (Cervantes-Ocampo, 2014). The city of Xalapa was outside of the transmission area until 2007, but in 2008, an outbreak of dengue was reported there for the first time, though there was no evidence of the presence of *Ae. aegypti* during those events. In 2011 *Ae. aegypti* was recorded for the first time in Xalapa and its surroundings. The capital city is touched by the upper margin of the current vertical distribution of *Ae. aegypti* in the state. Traditionally in Mexico, entomological surveillance and studies of dengue have been conducted in areas where there is a high, regular incidence of outbreaks. Because of that, studies conducted on the edges of the vector's distribution are rare in the country (Patz et al., 1998; Semenza and Menne, 2009; Banu et al., 2011).

Therefore, our goal for this paper is to obtain a glimpse of the changes in the relevant processes currently occurring in Mexico, by monitoring *Ae. aegypti* in Veracruz to better understand the underlying drivers for its establishment, and by using species distribution modelling and climate modelling to identify current and future areas at risk of *Ae. aegypti* establishment in central Veracruz, as well as a way to estimate the number of people potentially exposed to the expansion of its distribution.

The structure of this paper is as follows. The next section briefly outlines how the mosquito was monitored, with entomological indices for dengue transmission, and a detailed description of var-

ious species found under urban, semi-urban and non-urban land use. We discuss drivers such as land use changes, biodiversity loss, urbanization without sanitation, etc. The second section shows and discusses current and future maps of *Ae. aegypti* presence, both scenarios were produced from occurrence and environmental/climate data, which was then linked to the population exposed at the areas under *Ae. aegypti*'s expanded distribution area.

2. Methods

2.1. Entomological monitoring

2.1.1. Study area

The study was conducted in the city of Xalapa and its Metropolitan Zone in the state of Veracruz (Fig. 2). It is located in the central region of the state, in a mountainous area that includes part of the coastal slope of the trans-Mexican Volcanic Belt. Its landscapes include dry tropical forest, cattle pastures, cloud forest, and coniferous forest along an elevation gradient, but pristine ecosystems are now rare. Xalapa is located in the highlands of the Sierra Madre Oriental mountain range and spans elevations of 1300–1600 m a.s.l. The climate is temperate humid with summer rains. The original vegetation was predominantly cloud forest, one of the most biodiverse ecosystems of Mexico (Rzedowski, 1978). Coffee plantations are grown under shade at these elevations, but both cloud forest and coffee crops have nearly disappeared from the periphery of Xalapa due to incessant urbanization. Xalapa began to grow during colonization by the Spanish as it offered a refuge for immigrants and visitors above of the risky area on the lowlands around the port of Veracruz where yellow fever and malaria continuously affected people. The city eventually emerged as a trade center for imports from Europe. Alexander von Humboldt identified Xalapa as a safe place just beyond the area where the risk of catching one of these diseases was high. In general terms, our study system covers the Humboldt Road on the Port of Veracruz-Xalapa-Perote segment.

2.1.2. Elevation cline survey procedures

Fig. 2 shows the seven human settlements selected to explore the location of the elevation boundary of the vector's distribution using entomological and sociological surveys: 1) Rinconada (237 m a.s.l.), Municipality of Emiliano Zapata, which has a suboptimal urban infrastructure, was used as a positive control for dengue because there is a dengue outbreak there every year; 2) El Castillo (1140 m a.s.l.), municipality of Xalapa, located on the outskirts of Xalapa, and with few human settlements, almost no public services and small patches of different types of vegetation; 3) Camino a Rancho Viejo (1420 m a.s.l.), municipality of Xalapa, also on the outskirts of Xalapa, but with a predominantly natural ecosystem and no urban infrastructure; and inside Xalapa; 4) the suburb of Las Higueras (1200 m a.s.l.), haphazardly urbanized with poor public services and some patches of vegetation; 5) the suburb of Indeco Ánimas (1350 m a.s.l.), well urbanized, with reliable public services; 6) the Revolución suburb (1420 m a.s.l.), urbanized but with a suboptimal urban infrastructure; and 7) San Andrés Tlanelhuayocan (1659 m a.s.l.), Municipality of San Andrés Tlanelhuayocan, near Xalapa and surrounded by patches of cloud forest but whose urban infrastructure is suboptimal, but where there has been no record of dengue transmission (negative control).

2.1.3. Entomological survey

In each location, we randomly chose one hectare to conduct entomological sampling. We sampled all the water containers in the houses we visited. Samples were collected in August 2010 (the temperate, rainy season), March 2011 (cold, dry season) and May 2011 (hot, dry season), periods representative of the main weather conditions in the area throughout the year. Samples of immature

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