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Impact of road networks on the distribution of dengue fever cases in Trinidad, West Indies

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ABSTRACT

This study examined the impact of road networks on the distribution of dengue fever cases in Trinidad, West Indies. All confirmed cases of dengue hemorrhagic fever (DHF) observed during 1998 were georeferenced and spatially located on a road map of Trinidad using Geographic Information Systems software. A new digital geographic layer representing these cases was created and the distances from these cases to the nearest classified road category (5 classifications based on a functional utility system) were examined. The distance from each spatially located DHF case to the nearest road in each of the 5 road subsets was determined and then subjected to an ANOVA and *t*-test to determine levels of association between minor road networks (especially 3rd and 4th class roads) and DHF cases and found DHF cases were located away from forests, especially 5th class roads). The frequency of DHF cases to different road classes was: 0% (1st class roads), 7% (2nd class roads), 32% (3rd class roads), 57% (4th class roads) and 4% (5th class road). The data clearly demonstrated that both class 3 and class 4 roads account for 89% of nearby dengue cases. These results represent the first evidence of dengue cases being found restricted between forested areas and major highways and would be useful when planning and implementing control strategies for dengue and *Aedes aegypti* mosquitoes.

1. Introduction

Numerous factors have been found to influence the geographic spread of the mosquito *Aedes aegypti* L., the vector of urban yellow fever and dengue fever (Christopher, 1960) and these factors are integral to the transmission dynamics of dengue fever (Gubler and Kuno, 1997). Transmission of dengue fever is achieved primarily by the bite of an infected *Ae. aegypti* mosquito and within the Caribbean region over 908,926 cases of dengue fever (DF) and dengue hemorrhagic fever (DHF) cases have been reported in 2008 (WHO, 2010). Studies have shown dispersal of the vector, *Ae. aegypti* through anthropogenic means like air and sea transportation (Christopher, 1960; Gubler and Kuno, 1997; Le Maitre and Chadee, 1983; Chadee, 1984) and by eggs transported in artificial containers like drums and tires (Hughes and Porter, 1956; Haverfield and Hoffman, 1966; Chadee, 2003). Haverfield and Hoffman (1966) demonstrated the importance of shipments in the dispersal of *Ae. aegypti* (L.) in Texas, and suggested that the mechanism might also be significant at the interstate and international level. Studies in Australia and parts of northeast India have also shown a greater prevalence of *Ae. aegypti* along roadways, associating prevalence with the movement of people (Mackenzie et al., 1996; Dutta et al., 1998). These dispersal mechanisms are major risk factors for introduction, establishment and spread of both the *Ae. aegypti* vector and the dengue fever virus.

The *Ae. aegypti* flight range has been measured during various studies using mark-release-recapture, rubidium markers, molecular genetic markers and more recently sticky traps (Chadee and Ritchie, 2010). Christopher (1960) reported that *Ae. aegypti* seldom disperse more than 100 m and similar results have been reported in Mexico (Ordonez-Gonzalez et al., 2001) with maximum dispersal distance being 120 m when monitored by sticky traps. In contrast, a study in Puerto Rico (Reiter et al., 1995) recorded longer dispersal patterns of gravid females at 840 m but it is generally accepted that *Ae. aegypti* females do not disperse more than 300 m (Christopher, 1960).

In addition, recent studies have established that *Ae. aegypti* very seldom disperse to other geographic areas but are rather found within houses (Reiter and Gubler, 1997; Garcia-Rejon et al., 2008) and at the cardinal points of dengue case sites (Chadee et al., 2007). These studies have indicated that infected *Ae. aegypti* females may stay within premises 27 days post dengue transmission (Garcia-Rejon et al., 2008).

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The behavioral factors which influence the dispersal of *Ae. aegypti* mosquitoes include the flight associated with securing blood meals, like flying indoors, while oviposition flight is influenced by the availability of breeding sites like finding artificial water holding containers. Utilizing the need by female mosquitoes to forage for blood meals (Dunn, 1927) and the need to seek out oviposition sites (Chadee, 1997), a mark-release-recapture study reported that *Ae. aegypti* in Queensland, Australia readily crossed small quiet roads but avoided crossing a major highway near the release point and concluded that busy roads may impede dispersal (Russell et al., 2005). In a similar study, Laurance et al. (2009) investigated the impacts of roads and linear clearings in tropical forests and found various 'beetles, flies, ants, bees, butterflies, amphibians, reptiles, birds, bats and small and large mammals tend to avoid even narrow (<30 m wide) clearings or forest edges'. These results were confirmed by a study which examined the influence of a major highway in Trinidad on the population dispersal or dynamics of *Ae. aegypti* using a panel of microsatellites, two SNPs and a 710 bp sequence of mtDNA cytochrome oxidase and found strong evidence of limited gene flow across the highway, which effectively fragmented the population on the east and west side of the highway (Hemme et al., 2010).

These previous studies have examined the impact of roads on the dispersal of the vector of dengue fever but the impact of roads or landscape barriers on the transmission of dengue fever has never been reported and studies of this kind are long overdue. The results of these studies may well explain the clustering of dengue cases and identify the impediments faced by infected mosquitoes to distribute the infection to other geographical localities. The present study was conducted to investigate the impact of the different road networks on the distribution or dispersal of dengue fever cases in Trinidad, West Indies.

2. Materials and methods

2.1. Study area

Trinidad (10.5°N; 61.5°W) is the southernmost island within the Caribbean archipelago located northeast of Venezuela and separated by a distance of 15 km (Bradbury et al., 1981; Flenley, 1993) (Fig. 1). It is estimated that Trinidad became separated from the South American mainland some 11,000–15,000 years ago (Bradbury et al., 1981; Flenley, 1993) and the geology, flora and fauna on the island is basically continental (Mohan et al., 2009). Trinidad is rectangular in shape covering 4828 km^2 (TIDCO, 2006), with an estimated population of 1.2 million inhabitants (PROCICARIBE, 2006). One-third of the island is considered to be cultivable land (PROCICARIBE, 2006) while the remaining land surface is dominated by naturally occurring native vegetation making up an estimated 61.2% of the island (MALMR, 1995).

The island experiences a tropical climate with average daily temperatures ranging between 22 °C and 32 °C (Hoag et al., 2001) with two distinct seasons: a dry season from December to May, and a wet season from May to November (Mohan et al., 2009). Due to the prevailing northeast trade winds and orographic effects, the highland areas of northeast Trinidad receive up to 3800 mm per year of rainfall with precipitation ranging from 1250 mm in the northwest to 3000 mm in the southwest part of the island respectively (Hoag et al., 2001).

2.2. Case data

A definition of a confirmed DHF case was provided by the Ministry of Health, Insect and Vector Control Division. This definition was framed as persons (child or adult) having the symptoms; temperature of 38 °C or higher for 5 days, accompanied by headache, myalgia, and other non specific clinical presentations (Chadee, 2009; WHO, 2010). These persons were closely monitored for signs of hemorrhage. All suspected cases of DHF were laboratory confirmed by virus isolation, detection of specific IgM antibody and/or seroconversion (Chadee, 2009; WHO, 2010).

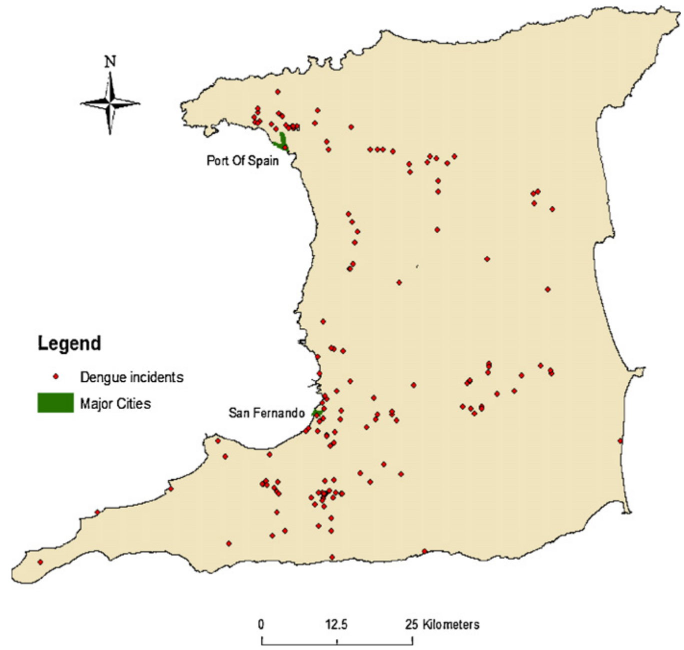

Fig. 1. Distribution of DHF cases in Trinidad (1998).

Records representing confirmed DHF cases for 1998 were collected from the Ministry of Health. These contained street addresses of persons confirmed to be infected by the disease. The year 1998 was specifically chosen because it represented a major outbreak of the disease in Trinidad.

2.3. Address geocoding

The street addresses of confirmed DHF cases were located on a Geographic Information System (GIS) road layer of Trinidad using the ArcGIS software. Successfully located cases were then plotted as point features; creating a new GIS layer representing point locations of DHF cases in Trinidad. Due to insufficient information in the DHF case records (e.g. missing addresses or much generalized locations such as city or county level) only 76.6% (157) of cases were geocoded. This had the net effect of making it almost impossible to get accurate home or work place addresses due mainly to poor standardization of data collection forms used in primary, secondary and tertiary care institutions.

2.4. Cluster analysis

In order to validate or confirm the data analysis, the Average Nearest Neighbor (ANN) method was used (Getis and Franklin, 1987) to determine whether the spatial distribution of dengue cases was due in part to chance or non-random spatial clustering. This method calculates a nearest neighbor index based on the average distance from each case to its nearest neighboring case. If the average distance is less than the average for a hypothetical random distribution, the distribution of the cases being analyzed are considered clustered, if not they are considered dispersed. The index is represented as the ratio of the observed distance divided by the expected distance (expected distance is based on a hypothetical random distribution with the same number of features covering