Associations between urban structure and *Aedes aegypti* larval habitats in Puntarenas, Costa Rica

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Abstract

Geospatial technologies have been increasingly applied to study vector-borne diseases, although their use in urban setting has been limited. In this study, high-resolution satellite imagery from QuickBird was analyzed to determine the relationships that urban structure, determined by tree cover and built area, may have with the abundance of mosquito larval habitats and the *Aedes aegypti* container index in an urban area of Costa Rica. Two cross-sectional entomological field surveys were performed in Greater Puntarenas during wet and dry seasons. A geographical sampling method was used to select the areas to be surveyed: a grid (100 by 100 meters) was constructed and a stratified random sample of 34 cells (10%) was selected. All possible larval habitats (wet habitats) were noted per cell, and mosquito larvae present were identified. Two seasonal land cover maps were prepared using QuickBird multispectral imagery with "water", "built", "tree", "grass/bare soil", and "paved" classes. The proportion of tree cover and built area was extracted for cells surveyed, and regression models were analyzed for the number of wet habitats, *Ae. aegypti* container index, and pupae per person. In the wet season and when corrected by the number of locations evaluated in each cell, tree cover (R^2 = 0.650, p<0.001) and built area (R^2 = 0.613, p<0.001) were able to significantly explain the variation in total habitats. These wet habitats were positively associated with tree cover and negatively associated with built area, while the *Ae. aegypti* container index was negatively associated with tree cover. The significant regression models were used to create maps of larval habitat abundance in Puntarenas at the cell level. Results showed that the abundance of mosquito larval habitats in urban environments may be explained and predicted by using remotely sensed information. Considering the associations found in this study, the areas at most risk would be those with an intermediate level of tree cover and built area and should be targeted for more efficient vector control.

Modeling and mapping of infectious diseases and vector distributions using remote sensing has been the focus of ongoing research for applications in public health. Dengue is the most important arboviral disease worldwide in terms of morbidity and mortality,[1] and *Aedes aegypti* is the principal vector. Recent studies have successfully related remotely sensed information of medium and low spatial resolution to mosquito habitats and disease.[2,3,4,5,6]

In Costa Rica, dengue is the most important vector-borne disease. Previous studies using high-resolution satellite imagery have associated tree cover to dengue incidence within the urban environment.[7] In this study, high-resolution satellite imagery from QuickBird was used to evaluate the relationships that urban structure, determined by tree cover and built area, may have with the abundance of mosquito larval habitats and *Ae. aegypti* container index in Greater Puntarenas, Costa Rica.

Materials and Methods

Total mosquito larval habitats and *Ae. aegypti* container index and pupae per person were calculated per cell using data obtained from cross-sectional field surveys performed in Greater Puntarenas during the wet season of 2006 and dry season of 2007.[8] During surveys, all possible larval habitats (wet habitats) per cell were searched, noted, and larvae were identified. The areas surveyed were selected using a geographical sampling method where a grid with cells of 100 by 100 meters was constructed, and a stratified random sample of 34 cells (10%) was selected (Fig. 1).[9] Land cover maps for wet and dry seasons were created from QuickBird multispectral bands (2.4 m spatial resolution) using the image classifier in eCognition software and with "water", "built", "tree", "grass/bare soil", and "paved" classes. Accuracy of the wet season map was 85.9% (Kappa=0.8), and accuracy of the dry season map was 90.6% (Kappa of 0.86). The proportion of tree cover and built area was extracted for each of the cells surveyed, and multiple linear regression models for each season were analyzed for the number of wet habitats, *Ae. aegypti* container index, and pupae per person. These models were applied to data extracted from the satellite imagery to create maps of the expected number of total wet habitats and *Ae. aegypti* container index. Resulting maps were overlaid to show areas (cells) expected to have a higher number of habitats containing *Ae. aegypti*.

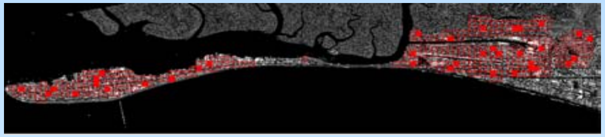

Fig. 1. Random sample of grid cells selected in Puntarenas for field studies and extraction of tree cover and built area from land cover maps.

Results

When the models included a correction variable for total locations (households, parks, streets, lots, fields, buildings, etc.) evaluated in the cell (LOCE), the wet season multiple regression models showed that tree cover (TREE) and built area (BUILT) were able to significantly explain the variation in total larval habitats, and tree cover explained variations in *Ae. aegypti* container index (Table 1). In the dry season, neither tree cover nor built area significantly explained the variations in total larval habitats or *Ae. aegypti* container index. The resulting significant models for the wet season were:

$$\#\ \text{larval habitats} = -10.187 + 35.933(\text{TREE}) + 1.716(\text{LOCE}) \quad (1)$$
$R^2 = 0.650$, F = 28.75, p<0.001

$$\#\ \text{larval habitats} = 10.314 - 30.465(\text{BUILT}) + 1.632(\text{LOCE}) \quad (2)$$
$R^2 = 0.613$, F = 24.55, p<0.001

$$\textit{Ae. aegypti}\ \text{container index} = 36.544 - 38.295(\text{TREE}) - 0.550(\text{LOCE}) \quad (3)$$
$R^2 = 0.188$, F = 3.59, p=0.040

Maps of Greater Puntarenas that resulted from applying the models showed cells expected to have more wet habitats (Figs 2 and 3), higher *Ae. aegypti* container index (Fig. 4), and more habitats positive for *Ae aegypti* (Fig 5).

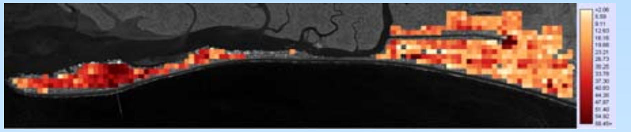

Fig. 2. Expected number of mosquito larval habitats (wet habitats) per cell in Puntarenas according to model #1.

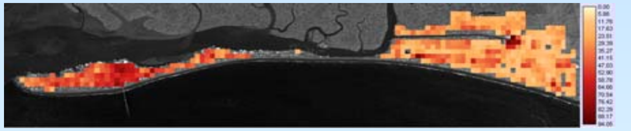

Fig. 2. Expected number of mosquito larval habitats (wet habitats) per cell in Puntarenas according to model #2.

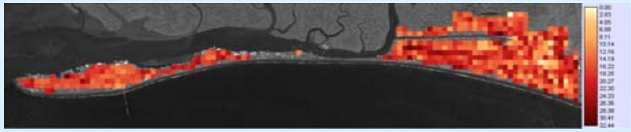

Fig. 4. *Aedes aegypti* container index expected per cell in Puntarenas according to model # 3.

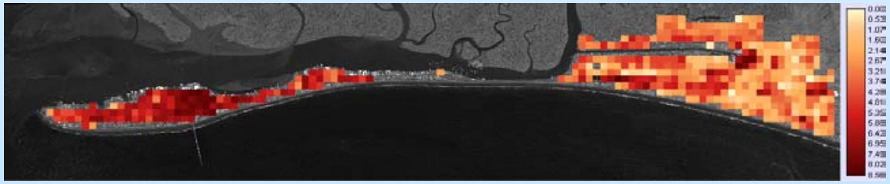

Fig. 5. Number of *Aedes aegypti* positive habitats expected per cell in Puntarenas (wet habitats*container index).

Conclusions

The multiple linear regression models were able to explain more than 60% of the variation in the number of larval habitats in the cells surveyed during the wet season. In general, more tree cover suggested more wet habitats when controlling for the number of locations, and a high proportion of built area suggested fewer habitats. These results agree with previous observations in which dengue fever was directly correlated with tree cover and indirectly with built area.[7]

The container index for *Ae. aegypti* was inversely associated with tree cover, which may suggest that females oviposit in most of the containers present. Considering the two opposite associations found with tree cover in this study, the areas at most risk would be those with an intermediate level of tree cover and built area. In addition, no association was clear in the dry season, and the distribution of mosquito larval habitats is probably more associated with human behavior than environmental conditions or urban structure.

Results show that remotely sensed information can be used to explain and map the abundance of mosquito habitats in urban environments such as Greater Puntarenas. With maps and models such as these, urban areas can be evaluated and specific areas identified using remotely sensed data to achieve more efficient vector control interventions.

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