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An entomological surveillance system based on open spatial information for participative dengue control

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ABSTRACT

Aedes aegypti is a very efficient disseminator of human pathogens. This condition is the result of evolutionary adaptations to frequent haematophagy, as well as to the colonization of countless types of habitats associated with environmental and cultural factors that favor the proliferation of this mosquito in urban ecosystems. Studies using sensitive methods of monitoring demonstrate that the methods of surveillance used in the Brazilian program do not show the high degrees of the infestation of cities by this vector. To increase the capacity of the health sector, new tools are needed to the practice of surveillance, which incorporate aspects of the vector, place and human population. We describe here the SMCP-*Aedes* – Monitoring System and Population Control of *Aedes aegypti*, aiming to provide an entomological surveillance framework as a basis for epidemiological surveillance of dengue. The SMCP-*Aedes* is uphold in the space technology information, supported by the intensive use of the web and free software to collect, store, analyze and disseminate information on the spatial-temporal distribution of the estimated density for the population of *Aedes*, based on data systematically collected with the use of ovitraps. Planned control interventions, intensified where and when indicated by the entomological surveillance, are agreed with the communities, relying on the permanent social mobilization.

Key words: dengue vector, entomological surveillance, ovitraps, GIS, vector control.

INTRODUCTION

According to the World Health Organization, over 40% of the world's population is at risk of acquiring dengue and there may be 50 million of new dengue infections every year. Innate characteristics of the dengue virus (DENV), which exists in four serotypes and can cause up to four infections *per* person, and of its main vector, *Aedes aegypti*, considered an extremely efficient disseminator of human pathogens, accounting for the expansion of the geographic distribution and, consequently,

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for the dramatic growth of the global burden of dengue in the last decades. *Ae. aegypti* is a highly anthropophilic species that feeds almost exclusively on humans (Scott et al. 1993, 2000, Harrington et al. 2001, Ponlla-wat and Harrington 2005). According to Harrington et al. (2001), the unique isoleucine concentration on human blood is associated with *Ae. aegypti*'s unusual propensity to feed preferentially and frequently on humans – a behavior that increases this mosquito's fitness and, thus, is an underlying reason for its intimate contact with human hosts. The authors highlight that "from a public health perspective, selection for frequent human contact and an age-dependent increase in feeding frequency magnify the potential for transmission of pathogens by older potentially infected mosquitoes". Upon studying the blood meal frequency of *Ae. aegypti* field populations in Thailand, Scott et al. (2000) estimated that a female takes on average 0.76 human blood meal *per* day. These biological features of the vector have high epidemiological significance, and explain why *Ae. aegypti*'s territory is the human house, from which it seldom leaves.

Evolution-driven adaptations to unstable habitats are also important factors to understand the role of this species as an efficient vector of pathogens: *Ae. aegypti* is an opportunistic container breeder. This mosquito is able to colonize all types of water holding containers; presents a fantastic resistance of its eggs chorion and the "skip oviposition behavior" of females (i.e. the spread of eggs from the same batch on different containers); and its larvae and pupae have the ability to dive deeper and for longer periods than other mosquito species (Koenraadt and Harrington 2008). It is crucial to consider these biological aspects and the consequences of their combination with environmental and climatic factors, as well as with anthropogenic habits that favor the mosquito proliferation, in order to understand the expansion and intensification of dengue and, most important, to choose adequate strategies and methods to monitor and control *Ae. aegypti* populations.

A protective tetravalent vaccine must be available if dengue is to be controlled. There are promising vaccine candidates under development (Trindade et al. 2008) and there is a possibility that this will be achieved in a few years (Whitehead et al. 2007, Edelman 2007). However, the well established *Ae. aegypti* populations in urban environments will remain as a matter of concern since other arboviruses may be transmitted by this species, such as Chikungunya and West Nile viruses.

The presence of this mosquito species was detected in 60% to 90% of the houses in Brazilian cities where sensitive surveillance methods were utilized to monitor *Ae. aegypti* populations, such as Salvador (Morato et al. 2005), Manaus (Ríos-Velasquez et al. 2007) and Recife (Regis et al. 2008). At the same time, the House Index (HI), used by the Brazilian National Program for Dengue Control, showed for these places negative or low values, seldom more than 10%. The lack of sensitivity of entomological indices based on the visualization of immature stages, like the HI and the Breteau Index, is attributed to: a) the strong sensitivity and responsiveness of aedine pre-imaginal forms to water surface vibrations (Shuey et al. 1987), and their ability to make deep and long-duration dive and to perform bottom-resting (Romoser and Lucas 1999), thus making their visualization difficult; b) the information generated is the percentage of house/containers where the presence of one (or more) larva/pupa is observed during a visit that lasts a few minutes and takes place at every two months.

Despite its lack of sensitivity for detecting the presence of *Aedes*, and the fact that it does not quantify population size or density, this method proposed eight decades ago (Connor and Monroe 1923) is the only entomological surveillance tool used in most programs.

The complexities of the new urban realities point out new targets to the control of mosquito born diseases, such as dengue fever. To increase the capacity of the health sector for controlling transmissible diseases, new tools for epidemiological practice and surveillance must be developed. The SMCP-*Aedes* – System for Monitoring and Control of the Population of *Aedes aegypti* – is a contribution in this direction.

Dengue vector surveillance is important to determine when and where to apply the control actions. An entomological surveillance system able to generate quantitative information on mosquito population densities and helping to predict explosive population growth is essential for launching actions to prevent epidemics to occur. The importance of the entomologic surveillance as a base for dengue transmission control has been recently highlighted by Ooi et al. (2006).

THE SMCP-*Aedes*, A SPATIAL SURVEILLANCE SYSTEM

The main underlying concept within the SMCP-*Aedes* is to integrate biological aspects of the vector with human population and environmental data through building an entomological surveillance system based on geographical information, as a support for dengue epidemiological surveillance and control at intra-urban scales. To do so, the SMCP-*Aedes* makes intensive use of open spatial technology solutions. It is based on open protocols and open standards, an intensive use of web and open software for GIS and Database Management working-up information stored in a spatial-temporal database from where they can be explored through quantitative methods. The *Aedes* population in a certain urban area can be estimated and its spatial-temporal distribution visualized, based on continuous eggs collection. Control interventions can be planned and intensified on the basis of spatial analysis carried on by the SCMP-*Aedes*. These actions to be taken by the local health services can be agreed with the local community. In this sense, the SMCP-*Aedes* can be instrumental for helping the building-up of a permanent social mobilization towards a more effective vector control.

The sample design was conducted supposing to overlap a grid with 400 cells with 50m × 50m each one, for a territory of 1 km^2. Depending on the household density in the area, the sample size (number of cells) was calculated by fitting a logistic function (Fig. 1), taking into account the following parameters: 10 cells for very low densities (i.e. 100 or less households *per* km^2); 100 cells for intermediate density (i.e. almost 3.000 households *per* km^2) as adopted in a previous experiment (Regis et al. 2008); and an upper boundary of 200 (50% of the total) cells for very high densities.

$$Y = \frac{1}{\frac{1}{u} + b_0 \times b_1^X}$$

where Y is the number of cells to be sampled which will receive one ovitrap; u is the upper boundary; X is the mean number of households *per* km^2; and b_0 and b_1 are the parameters estimated by the model.

Each trap was allocated inside the cell space and the coordinates of the location was taken using a Global Positioning System (GPS) and recorded at an integrated geographic information system.

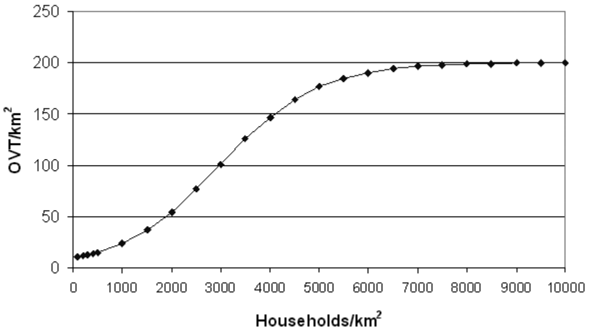

Fig. 1 – Logistic function describing the number of cells to be sampled according to the household density.

A sensitive, safe, low cost and easy to use tool is suitable for continuous egg-collection at a number of fixed sampling stations in order to monitor reproductively active populations. This can be accomplished with an ovitrap model consisting of a black plastic cup baited with 2 L of grass infusion (or water supplemented with alfalfa pellets) treated with a Bti-based product and containing three 5 × 15 cm wooden paddles, as oviposition substrates (Regis et al. 2008). Besides being a potent, safe and long lasting larvicide specially under shade (Regis et al. 2001, Araújo et al. 2007, Melo-Santos et al. 2009), Bti seems to act as an oviposition stimulant (Santos et al. 2003, Stoops 2005), giving increased efficiency to the trap, which can safely remain in the field for up to two months showing an egg-collection capacity of over 7.000 eggs/trap-month (Regis et al. 2008). An egg counting computer-assisted system (Mello et al. 2008) allows operational advantages over the optical microscopic counting system. It is less time-consuming and data records are directly transferred to a geographical database.

THE SMCP-*Aedes* CONCEPTUAL ARCHITECTURE AND OPEN TECHNOLOGIES

The decision on supporting technology for the SMCP-*Aedes* is based around open software and open standards for geospatial data. It goes in line with our previous work in Recife (Regis et al. 2008) and with the recent works linked with health information systems that have taken the same lines (Qian Yi et al. 2008, Moreno-Sanches et al. 2007). The database logic model has been based upon the Recife-SAUDAVEL-GED. For the first version of the SMCP-*Aedes*, we have taken the open MySQL Database Server as the repository for the geographic entomological database. The MySQL DBMS software is embedded by the open TerraLib GIS library (www.dpi.inpe.br/terralib) allowing for the spatial-temporal models to store, retrieve and analyze the data. The eggs counts are recorded on the database by using a web-based interface that has been developed by the SAUDAVEL network (Monteiro et al. 2005) at the National Institute for Spatial Research – INPE and at CPqAM/Fiocruz and adapted for this system. The database contains other data as demographic data at the census tract scale, satellite images of the region and all mapping information available for the sites where the ovitraps have been installed. We have adopted TerraView (www.dpi.inpe.br/terraview), an open GIS application that runs on desktop computers, as a browsing tool for this geographic database which provides quick summaries for some spatial-temporal queries in the stored data, and an integrated environment for visualization of data, remote sensing satellite imagery, pictures of the traps and census tract data.

Within the SMCP-*Aedes* system, assessments and decision making are based on reports that are produced systematically and automatically incorporating the latest available data. Typically, such outputs make use of statistical analysis and modeling tools beyond the GIS capabilities which are implemented by scripts (Bonat et al. 2008) which are written using the R statistical computing language (R DEVELOPMENT CORE TEAM 2009). Such scripts can be modular, implementing requested analysis and the associated reporting formats running automatically on the data base server. The R add-on package aRT (Andrade et al. 2005) provides a software binder for integrating TerraLib GIS library and R. Specific routines for statistical, and in particular spatial and/or temporal analysis, are implemented by another R package, RDengue, tailored to the specific needs of the project and designed to release automatic analysis of the data stored into the SMCP-*Aedes* geographical database (Dallazuanna et al. 2008). Figure 2 displays a schematic view of this architecture and detailed schemes; and some example outputs can be seen in Figure 3.

INTEGRATED VECTOR CONTROL BASED ON ENTOMOLOGICAL SURVEILLANCE

The National Program of dengue control, PNCD, established in Brazil in 2002, is implemented by the Ministry of Health in partnership with the 27 states and 5,560 municipalities. The PNCD foresee the implementation of vector control activities, among other components. The vector control is based essentially on the work of health workers carrying out registration of houses and the use of temephos as larvicide. In the last 12 years, large amounts of organophosphates have been routinely applied in cycles of two months with high operational cost. Other insecticides (organophosphates and pyrethroids) are used as adulticides. The application of larvicides and adulticides will hardly reach the control pressure to reduce populations of this species in a satisfactory way due to known behavioral and biological characteristics, peculiar to *Ae. aegypti*, in addition to the fact that mosquito populations develop inevitably a resistance to these compounds, as has been detected in the country since 2000.

The vector control measures proposed here are based on the temporal and spatial distribution of reproductively active mosquito populations, as estimated from eggs collected in the sentinel ovitraps. The aim is to prevent mosquito population outbreaks associated with the seasonal increase of dengue cases by intensifying control measures in specific places at specific times. In Recife, it was observed that the first rainfall after the dry season, associated with the season's high temperatures promoting a massive mosquito egg hatching, resulted in very high mosquito densities from January to August, which match the dengue season. As we have experimentally demonstrated in an urban neighborhood (Regis et al. 2008), such a vector population boost can be prevented through egg mass collection using 4,000 control-ovitraps / km^2. At the same time, entomological spatial analysis in seven different urban sites in Recife allowed the identification of intra-site areas where mosquito populations were persistently most concentrated (Regis et al. 2008).

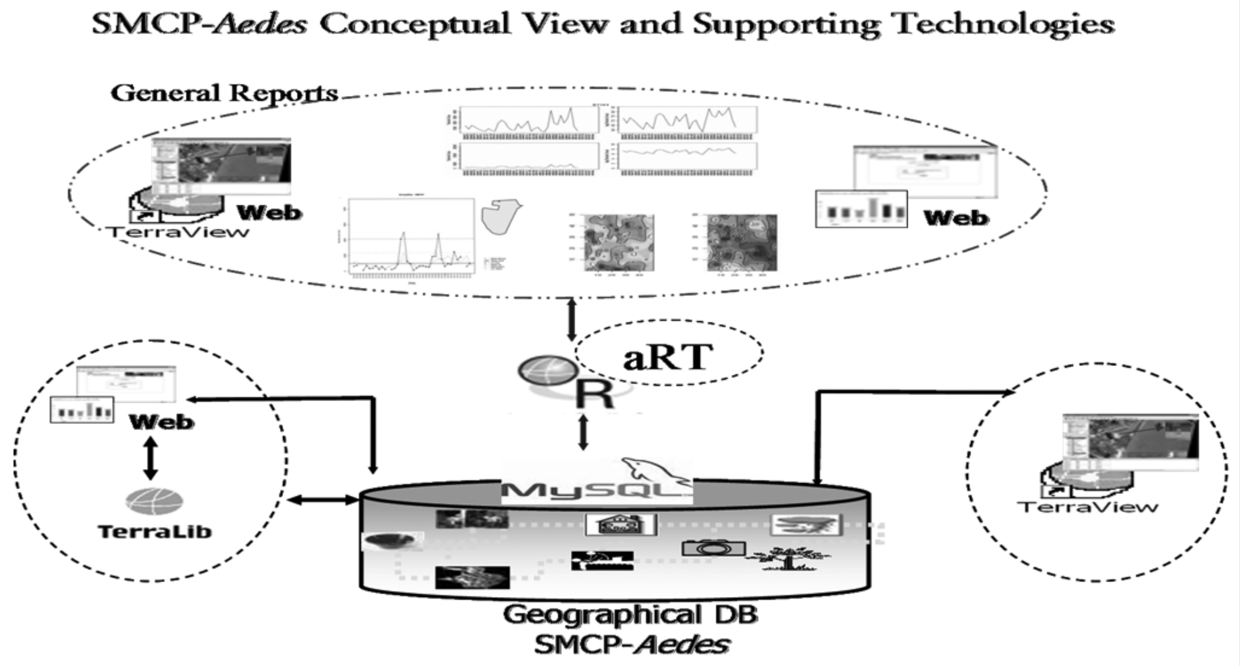

Fig. 2 – A General Conceptual Scheme for the Computational Architecture of the SMCP-*Aedes* including the open set of spatial technologies chosen for implementation of the system. It involves open GIS library TerraLib, the open GIS application TerraView, the open database management system MySQL and the aRT – an Application Programming Interface for binding R to TerraLib running the RDengue statistical analysis package.

The strategy proposed in the SMCP-*Aedes* is to combine larval source reduction by eliminating, properly covering or applying Bti as a larvicide in potential larval habitats, with mass collection/destruction of eggs, through an agreement between public health services and the local community. In this strategy, the use of ovitraps is essential to avoid gravid females to disperse in the search for oviposition sites. The public must be aware that the lower the amount of available breeding sites in a house, the higher the amount of eggs that will be laid in an ovitrap. Another important aspect is that the oviposition substrate used in these ovitraps (cotton fabric, according to Lenhart et al. 2005) allows the visualization of *Aedes* eggs by the householders, and it is easier to be incinerated (for egg destruction) than wooden substrates. For security reasons, the Government should take responsibility for egg incineration and supply of larvicides based on Bti to be used in the ovitraps.

Besides these actions, aiming to avoid a general mosquito population growth, the strategy also includes control interventions targeting the hotspots and focusing on mechanical elimination of adult mosquitoes from houses located in these areas. The use of aspirators for indoor collection of adult mosquitoes has several advantages over the use of organophosphorous or pyretroids as adulticides: it does not offer any health risk for humans and domestic animals; the method is efficient and effective since mosquitoes are caught directly from their resting places within the house; householders are able to see the mosquito capture; and results are measurable. It is expected that the vector population is impacted by indoors mosquito captures repeated fortnightly for two consecutive months within houses containing two or three ovitraps for egg collection-destruction and where potential breeding sites are properly managed. These control strategies are currently under evaluation in a large-scale pilot experiment in two cities of Pernambuco, Brazil.

FINAL REMARKS

Built on an interdisciplinary approach, the SMCP-*Aedes* was developed and assessed based on a longitudinal study conducted at Recife-PE over a 4 years period (Regis et al. 2008). It has now been putting into action as a pilot program in two cities of the Pernam-

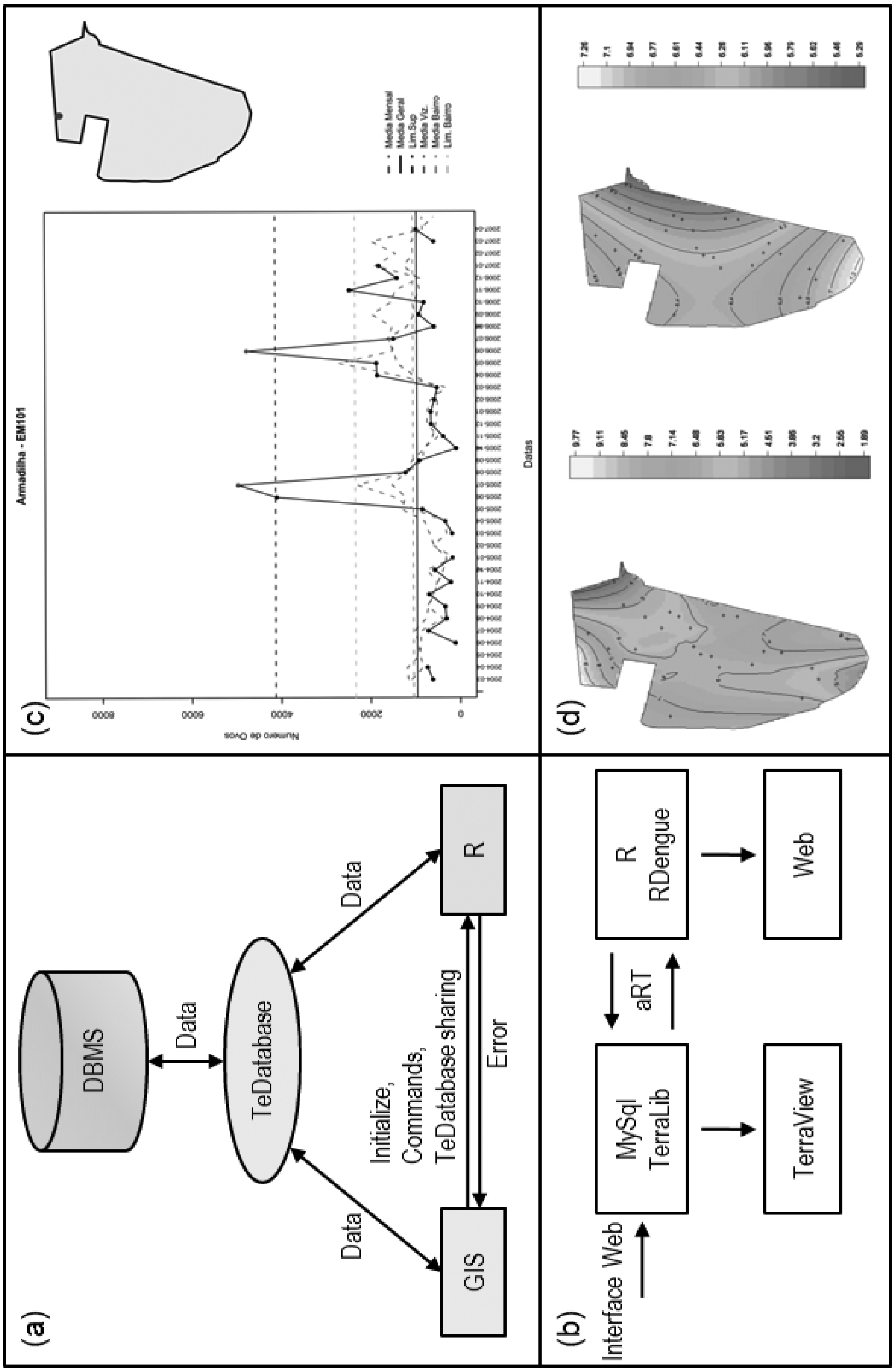

Fig. 3 – (a) A simplified scheme showing the interaction amongst an open DBMS system, the open TerraLib GIS library and the open statistical computing environment R; (b) A schematic view on how the open technologies work together to promote spatial analysis and visualization of the entomological and geographical data; (c) An example of analysis carried out by the RDengue to a specific ovitrap showing its placement and statistical summaries relating the average egg counting on that trap against its neighbors over time; (d) Another example of RDengue possibilities showing a *hotspot* map for a specific site that displays the estimated vector density based on the ovitraps counting over a certain period.

buco state, Brazil, in a joint effort involving the state health authority, the local health services, research institutions (Fiocruz and INPE) and the SAUDAVEL network (Monteiro et al. 2005). The system is designed to generate automatic analysis and reports. Besides, it uses open software produced in Brazil namely the TerraLib/TerraView, aRT and RDengue, combined with a R software for statistical computing and a database management system. The following-up of the outcomes of the program in the pilot cities of Santa Cruz do Capibaribe-PE and Ipojuca-PE is expected to demonstrate how open spatial information technology can contribute to establish an entomological surveillance strongly based on open spatial technology solutions with low cost and high efficiency.

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RESUMO

Associadas a fatores bióticos, climáticos e culturais que favorecem a proliferação do *Aedes aegypti* em ecossistemas urbanos, adaptações evolutivas à hematofagia freqüente e quase exclusiva em humanos e à colonização de tipos infinitos de habitats, fazem deste mosquito um disseminador extremamente eficiente de patógenos ao homem. Estudos utilizando métodos sensíveis de monitoramento demonstram que os métodos de vigilância usados no programa brasileiro não revelam as elevadas intensidades da infestação das cidades por este vetor. Para ampliar a capacidade do setor de saúde novos instrumentos são necessários à prática da vigilância, incorporando aspectos do vetor, do lugar e das pessoas do lugar. Apresentamos aqui o SMCP-*Aedes* – Sistema de Monitoramento e Controle Populacional do *Ae. aegypti*, cuja meta é a instrumentalização da vigilância entomológica como base para a vigilância epidemiológica da dengue. Para isso ele se apóia em tecnologias da informação espacial baseadas no uso intensivo da *web* e de *software* livre para coletar, armazenar, analisar e disseminar informações relativas à distribuição espaço-temporal da densidade estimada para a população do *Aedes*, com base em amostras obtidas continuamente com ovitrampas. Intervenções de controle planejadas e intensificadas onde e quando indicado pela vigilância entomológica, são pactuadas com os habitantes, apoiando-se na mobilização social permanente.

Palavras-chave: vetor da dengue, vigilância entomológica, ovitrampas, SIG, controle do vetor.

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