Acta Tropica 209 (2020) 105543

Contents lists available at ScienceDirect

Acta Tropica

journal homepage: www.elsevier.com/locate/actatropica

Use of an Extended Premise Condition Index for detection of priority areas for vector control actions

Gerson Laurindo Barbosa[a], Mariana de Oliveira Lage[b], Valmir Roberto Andrade[c], Antônio Henrique Alves Gomes[d], Jose Alberto Quintanilha[e], Francisco Chiaravalloti Neto[f,*]

[a] Superintendência de Controle de Endemias, Secretaria de Saúde do Estado de São Paulo. Rua Paula Souza, 166, São Paulo, SP, Brazil, 01027-000
[b] Programa de Pós-graduação em Ciência Ambiental, Universidade de São Paulo. Avenida Professor Luciano Gualberto, 1289, São Paulo, SP, Brazil, 05508-010
[c] Serviço Regional de Campinas, Superintendência de Controle de Endemias, Secretaria de Saúde do Estado de São Paulo. Rua Fernão Pompeu de Camargo, 372, Campinas, SP, Brazil, 13041-025
[d] Superintendência de Controle de Endemias, Secretaria de Saúde do Estado de São Paulo. Rua Paula Souza, 166, São Paulo, SP, Brazil, 01027-000
[e] Instituo de Energia e Ambiente, Universidade de São Paulo. Avenida, 1289, São Paulo, SP, Brazil, 05508-010.
[f] Faculdade de Saúde Pública, Universidade de São Paulo. Avenida Doutor Arnaldo, 715, São Paulo, SP, Brazil, 01246-904

ARTICLE INFO

Keywords:
Aedes aegypti
vector control
dengue fever

ABSTRACT

The Premise Condition Index (PCI), proposed by Tun-Lin and colleagues in 1995, is a score that considers the conditions of a premise as well its yards and degree of shading. They hypothesized that the higher its value the greater the probability of the premise having the presence of *Aedes aegypti*. This study aimed to evaluate if there is a correspondence between PCI and *Ae. aegypti* infestation in four areas of a large city in the State of São Paulo, Brazil, if the inclusion of new categories related to the presence of animals in premises would increase the probability of detecting predictive areas for vector control actions and, if so, to propose an expanded PCI. The positivity of the premises for the presence of Ae. aegypti was modeled considering a Bernoulli probability distribution, in a Bayesian context using the Integrated Nested Laplace Approximation. The study showed that, in general, the higher the value of the PCI of a premise, the more likely it is to have the presence of *Ae. aegypti*, and the inclusion of information on the animals' presence can increase the discriminatory power of PCI. These results support the proposition of an extended PCI that would consider, in addition to the conditions of the premise, the presence of animals to classify it regarding the risk of the presence of *Ae. aegypti*.

1. Introduction

Strategies to prevent dengue fever are based on vector control through integrated action management, active search for cases based on an adequate health information system, emergency preparation, capacity building and training of agents responsible for actions, and developing research in vector control. Vaccines are currently being developed for dengue control, but there are many challenges to be overcome, such as the immunological response in patients who have never had dengue fever (Vannice et al., 2016). Moreover, there is recent information from the National Health Surveillance Agency that considers the possibility of a vaccinated individual who has never had dengue to acquire a more severe form of the disease in case of contact with the virus through the bite of the transmitting mosquito (Rocha, 2017). Thus, it can be said that there are few alternatives currently to reduce or prevent the transmission of the virus (if not by vector control), and what is observed is that prevention programs have been insufficient and ineffective (Guzman et al., 2010). For example, Olliero et al. (Olliaro et al., 2018) in a systematic review did not find robust studies on the impact of fogging on transmission control, which shows the need for greater investment in vector control.

The lack of an impact evaluation of the measures adopted in *Aedes aegypti* control program may be one of the reasons for the difficulty in controlling the mosquito and reliable as well as practical indicators are needed (Barrera, 2016). An important limitation of larval indicators is that they depend on the visual location of the breeding sites, which do not reflect the true prevalence of *Ae. aegypti* when there are critical breeding sites, that is, those with difficult access that are not always visually identified (Barrera, 2016; Bermudi et al., 2017).

Considering these aspects, the question arises regarding potential

* Corresponding author: Francisco Chiaravalloti Neto; Avenida Doutor Arnaldo, 715, São Paulo, SP, Brazil, 01246-904.
E-mail addresses: gersonlbarbosa@yahoo.com.br (G.L. Barbosa), mariana_lage@usp.br (M.d.O. Lage), valmir@mpc.com.br (V.R. Andrade), goreau@terra.com.br (A.H.A. Gomes), josealberto.quintanilha@gmail.com (J.A. Quintanilha), franciscochiara@usp.br (F. Chiaravalloti Neto).

https://doi.org/10.1016/j.actatropica.2020.105543
Received 19 February 2020; Received in revised form 14 May 2020; Accepted 14 May 2020
Available online 26 May 2020
0001-706X/

Ae. aegypti breeding sites available on the premise. The possibility of finding premises that, due to certain characteristics, may offer more mosquito breeding sites could help the vector control program, reducing resources and the time spent eliminating them. Thus, Tun-Lin et al. (Tun-Lin et al., 1995a) presented an index known as the Premise Condition Index (PCI), which considers the conditions of the premise as well as its yard and degree of shading by assigning a standard score for this information and defines an index that may be related to the supply of containers. Tun-Lin et al. (Tun-Lin et al., 1995b) further demonstrated in another study that there is some degree of stability concerning positive households by classifying them as key premises, and these premises, or certain types of containers, contribute disproportionately to the maintenance of *Ae. aegypti* population. Chadee et al. (Chadee, 2004) also assessed the presence of the key premises in a study conducted in Trinidad and suggest that focusing efforts on these premises to control mosquito density may be more cost-effective.

Peres et al. (Peres et al., 2013) conducted a study in municipalities in the northern region of Rio de Janeiro, Brazil, and found as the number of eggs in oviposition traps increased, the PCI also increased, showing that the PCI can be used as an indicator of the presence of breeding sites and mosquitoes. Another study showing a positive relationship between the presence of adult larvae, pupae and mosquitoes and PCI values was performed in the municipality of Marília, State of São Paulo, Brazil (Andrighetti et al., 2009). Also, Nogueira et al. (Nogueira et al., 2005) in Botucatu, State of São Paulo, found the same association between the presence of *Ae. aegypti* eggs and the PCI.

Despite these studies, the use of the PCI in the activity routine of the Brazilian Vector Control Program has not yet been effective, because it still needs further studies for its validation and better adaptation to housing conditions and Brazilian customs and practices. One possibility would be the inclusion of components in the PCI that represent the widespread behavior in Brazilian society of keeping animals in their homes (Bortoloti and D'Agostino, 2012; Schoendorfer and Germano, 2001). In this regard, a study conducted in a medium-sized municipality in the state of São Paulo showed that the presence of dogs and chickens increased the chance of finding the vector in the premises in 51% and 103%, respectively (Favaro et al., 2013).

Once it is shown that increasing PCI values are directly related to the increased probability of *Ae. aegypti* identification on premises, this indicator has the potential to be used to identify areas of higher risk within municipalities for the presence of the vector, which could optimize its control. However, studies so far have not taken into account the spatial dependence of the studied phenomenon (Andrighetti et al., 2009; Nogueira et al., 2005; Peres et al., 2013), an important step for the validity of the indicator.

To better validate the PCI and evaluate the inclusion of other components in the PCI composition, this study aimed to evaluate if there is a correspondence between PCI and *Ae. aegypti* infestation in four areas of a large city in the State of São Paulo, if the inclusion of new categories regarding the presence of animals in premises in the PCI would increase the probability of detecting predictive areas for vector control actions and, if so, to propose an expanded PCI.

2. Methodology

The present study was conducted in the municipality of Campinas, State of São Paulo, southeastern Brazil (Figure 1), located at 22º57′ south latitude and 47º07′ west longitude. The city has the third largest population in the State with just over one million inhabitants and has a high human development rate (0.805). Its climate is hot and temperate, with annual average temperature and precipitation of 19.3ºC and 1315 mm, respectively.

Four areas were selected to assess the premise infestation by *Ae. aegypti*, (Figure 1) with different socioeconomic levels and the presence, or not, of strategic points at different risks for the presence of the vector. The strategic points are properties, like tire shops and deposits, building material companies and recyclable material deposits, with a large amount of potential breeding sites for the immature forms of the mosquito (Barbosa et al., 2019). Area 1 had the best socioeconomic level according to the census of the Brazilian Institute of Geography and Statistics (IBGE) held in 2010, with an average income of R$1807.00 and 3.0 residents per household; areas 2 and 3, with an intermediate level, had rents of R$1285.00 and R$1138.00 and 3.2 and 3.4 residents per household, respectively; and area 4, with the worst level, had an average income of R$ 755.00 and 3.5 residents per household. Also, area 1 did not have the presence of strategic points, and areas 2, 3 and 4 had strategic points with low, medium and high risk for the presence of the vector, respectively.

The study was developed in 3-month cycles from October 2015 to March 2016, during spring/summer, which is considered more favorable for the development of the vector (Chadee, 2004; Dowling et al., 2013; Favaro et al., 2013; LaDeau et al., 2013; Little et al., 2017; Barbosa et al., 2019; Lorenz et al., 2020). A factor that could influence the abundance of the vector in periods other than spring and summer would be the population's need to store water in periods of drought, which coincide with winter in the southeastern Brazil. However, this is not the case of Campinas, since the city has no water supply problems, which has coverage, according IBGE, of 99.55%. Each of the premises of the four areas was visited twice and, at each visit, trained staff members searched for potential *Ae. aegypti* containers and, when encountering mosquito larvae and/or pupae, collected samples, which were sent to the laboratory for identification. They also identified the presence of dogs, chickens, and other animals and classified the household according to the PCI components, as proposed by Tun-Lin et al. (Tun-Lin et al., 1995a) below:

- Condition of the premise - Values from 1 to 3 were assigned, with 1 for a well-maintained household (i.e., new painting or new household); 2 for a moderately maintained household and 3 for a poorly maintained, cracked, dilapidated household;
- Backyard condition - Values from 1 to 3 were assigned, with 1 for a well-maintained yard, no apparent waste, and well-maintained garden; 2 for a moderately well-maintained yard and 3 for a poorly maintained yard, apparent trash, etc;
- Shading condition - Values from 1 to 3 were assigned, with 1 for little or no shading ($<$ 25% of the premise); 2 for moderate shading (between 25 and 50%) and 3 for shading $>$ 50%.

The geographical coordinates of the households were obtained through a portable mobile device at the time of visits, and all collected information was also recorded in these devices. At the end of each working day, all this information was downloaded to a database. Laboratory information on the positivity of containers for *Ae. aegypti* immature forms was added to the data collected in the field.

Premises with one or more breeding sites with immature forms of *Ae. aegypti* in at least one of the visits were classifed as postive and the others were classified as negatives. The values of the PCI components measured in each survey were compared, and when there was a difference in the PCI value, the average of this value was calculated. The value of the PCI of each premise resulted from the sum of the three components with an index, ranging from 3 to 9, with 3 being the best condition and 9 being the worst.

All information obtained was gathered in a final database, which was imported into a geographic information system (GIS), allowing the georeferencing of the worked premises from their geographic coordinates.

The positivity of the premise (Pos) for the presence of *Ae. aegypti* was modeled considering a Bernoulli probability distribution, according to equations 1 and 2 below:

$$Pos \sim Bern(\pi_i) \tag{1}$$

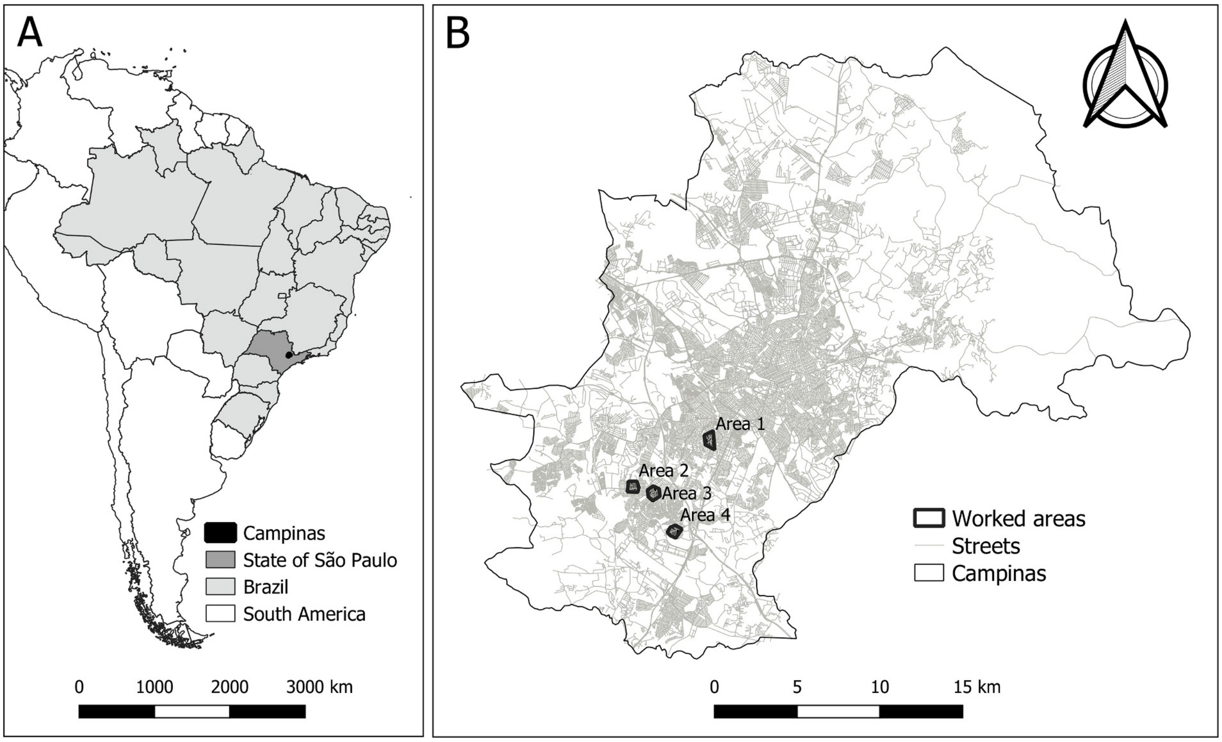

Figure 1. - Municipality of Campinas, State of São Paulo, Brazil, South America (A); the four areas assessed in the municipality of Campinas (B), as follows: Area 1, with the best socioeconomic level; Area 2 and 3, with intermediate socioeconomic levels; and Area 4, with the worse socioeconomic level.

$$logit(\pi_i) = \alpha + \sum_{p=1}^{p} \beta_p X_{pi} + EF + W(s_i) \quad (2)$$

where i = 1, ..., N represents each of the searched premises; π_i, the probability of the vector finding in a premise; and α, the intercept. β represents the regression parameters related to each of the covariates p (Xp) considered in the model - the type of area evaluated, the PCI and the presence of dogs, chickens, and other animals. EF represents the independent and identically distributed random effects (iid) related to the aggregation of premises in the four worked areas.

The Cartesian coordinates of each of the researched premises are represented by themselves, and W (si) represents the latent stationary Gaussian field that models the spatial dependence between the premises' location, so that:

$$W \sim MVN(0, \Sigma),$$

where, Σ is the spatially structured covariance matrix.

This matrix was modeled by a Matérn type function (Cressie, 1993), which considers Euclidean distances between premises. A Gaussian Markov random field represented the Gaussian field using the stochastic partial differential equations (Lindgren et al., 2011).

Initially, only one model with intercept, spatial autocorrelation and iid random effects was considered as a baseline for comparison with the other models containing covariates. Before considering the covariates in the models, an exploratory analysis of these covariates was performed to evaluate the relationship between them and the dependent variable and to verify the existence of collinearity between the covariates. The modeling was done in a Bayesian context using the Integrated Nested Laplace Approach (INLA) (Rue et al., 2009). For each covariate, posterior fixed effect averages and 95% credibility (CIs) intervals presented as odds ratios (ORs) were obtained. The best models with covariates were considered those with the lowest values of deviance information criterion (DIC) (Blangliardo and Cameletti, 2015).

Non-informative priors were assumed for fixed and iid random effects and priors with penalized complexity were considered for spatial random effects (Simpson et al., 2015). The modeling was performed using the statistical program R (R, 2019) and using the INLA library (www.r-inla.org). The program QGIS 3.4 (https://qgis.org/en/site/) was used as the GIS.

This study was submitted for approval by the Ethics Committee in *Plataforma Brasil* (Brazil Platform System), according to presentation certificate for ethical evaluation no. 43813015.9.0000.0059 and approved according to opinion no. 1.082.780.

3. Results

During the study period, 2213 premises were evaluated, and larvae of *Ae. Aegypti* were found in 227 of these premises, corresponding to a positivity of 10.3% (95% CI: 9.1-11.6). A summary of the entomological data obtained for the four areas is presented as Supplementary Material and the main findings are highlighted below.

Only *Ae. aegypti* and *Ae. albopictus* immature forms were found in the premises surveyed, more than 98% of then with *Ae. aegypti*. The majority of the breeding site with *Ae. aegypti* was classified as structural (59.3%), according to the classification used by (Little et al., 2017), and did not present differences among the four areas. The positive breeding sites classified as functional were more frequent than trash in areas 1 and 2 (with better socioeconomic levels) and the opposite occurred areas 3 and 4 (with worse socioeconomic levels) (Little et al., 2017). The majority of the potential breeding sites was classified as structural (61.7%), with area 2 presenting a higher value (70.1%) than the average value. The potential breeding sites classifies as functional presented decreasing frequencies with the worsening of socioeconomic levels and the opposite occurred with trash (Little et al., 2017).

Table 1 presents the positivity of premises according to areas, PCI, as well as the presence of animals. From the results obtained in each PCI category, it was observed that the average of positive containers for *Ae. Aegypti* immature forms in premises with a PCI ≥ 7 (16.3%) was almost double that observed in those with a PCI ≤ 7 (8.6%) and the same relationship occurred when analyzing the variables related to the

Table 1
Positivity of premises for *Aedes aegypti* according to covariates evaluated, Campinas, State of São Paulo, 2015-2016.

Covariates	Category	Positive premises		Negative premises		Total	
		N	%*	n	%*	n	%**
Study areas (AR)	1	46	12.3	329	87.7	375	16.9
	2	46	6.8	633	93.2	679	30.7
	3	68	10.9	554	89.1	622	28.1
	4	67	12.5	470	87.5	537	24.3
Premise Condition Indice (PCI)	3	33	7.1	433	92.9	466	21.1
	4	15	10.8	124	89.2	139	6.3
	5	73	9.1	727	90.9	800	36.2
	6	29	8.6	307	91.4	336	15.2
	7	58	15.3	321	84.7	379	17.1
	8	17	20.0	68	80.0	85	3.8
	9	2	25.0	6	75.0	8	0.4
Dog presence (DOG)	No	82	7.2	1057	92.8	1139	51.5
	Yes	145	13.5	929	86.5	1074	48.5
Chicken presence (CHK)	No	206	9.7	1918	90.3	2124	96.0
	Yes	21	23.6	68	76.4	89	4.0
Dogs and chickens presence (DOG_CHK)	Neither	77	6.9	1031	93.1	1108	50.1
	Dog or chicken	134	12.8	913	87.2	1047	47.3
	Both	16	27.6	42	72.4	58	2.6
Other animal persence (OTH)	No	207	10.0	1868	90.0	2075	93.8
	Yes	20	14.5	118	85.5	138	6.2
Presence of some animal (ANIM)	No	69	6.6	979	93.4	1048	47.4
	Yes	158	13.6	1007	86.4	1165	52.6
Number of animal species present (N_AN)	Neither	69	6.6	979	93.4	1048	47.4
	1	135	13.0	905	87.0	1040	47.0
	2 or more	23	18.4	102	81.6	125	5.6

* line percentage; ** column percentage

Table 2
Spearman correlation matrix for covariates considered as follows: study areas (AR), premise condition index (PCI), dog presence (DOG), chicken presence (CHK), dog and chicken presence (DOG_CHK), other animal presence (OTH), presence of some animal (ANIM) and number of animal species present (N_AN).

	AR	PCI	DOG	CHK	DOG_CHK	OTH	ANIM	N_AN
AR	1.00	0.34	0.11	0.11	0.13	0.04	0.11	0.13
PCI		1.00	0.12	0.15	0.15	0.07	0.14	0.16
DOG			1.00	0.07	0.96	0.01	0.92	0.90
CHK				1.00	0.32	0.13	0.19	0.32
DOG_CHKL					1.00	0.05	0.94	0.94
OTH						1.00	0.24	0.36
ANIM							1.00	0.97
N_AN								1.00

presence of animals. Table 2 presents the Spearman correlation matrix where some collinearities between variables were observed. Two or more collinear variables were not considered in the same model.

Table 3 presents the evaluated models with their respective DIC. All the models with covariates presented better DIC than the model with intercept and random effects. The two best models (with the lowest DIC), when compared to the model with the PCI and areas, were the models that included the presence of dogs and chickens (models 6 and 10). Among them, we chose the one with the presence of both in the same premise, model 10, because it best represented the interaction between these two variables.

Table 4 presents the unadjusted ORs for the models considering the positivity and each one of the covariates; the adjusted ORs for the model with the PCI and areas (model 2 of Table 3); and the adjusted ORs for the model with the PCI, areas and presence of dogs and chickens (model 10 of Table 3). It was observed, in the several models presented, that, except for area 2, the other areas did not present differences in the OR values. Regarding the PCI values, it was observed that PCI from 7 to 9 in the adjusted models had a dose-response effect, indicating that the higher the PCI is, the greater the risk of the presence of *Ae. aegypti*, highlighting that the OR for values 7 and 8 were significant. A PCI of 9 presented the highest OR values, but with a 95% wider amplitude CI associated with a small sample size (Table 1). Considering the presence of dogs and chickens, together or separately, an increased risk was also observed.

Table 3
Evaluated models and respective deviance information criterion (DIC) (all models included spatial random effect and iid random effect in the areas). The acronyms in the models represent the following covariates: PCI – premise condition index, AR – study area, DOG – dog presence, CHK – chicken presence, OTH – other animal presence, ANIM – presence of some animal and N_AM – number of animal species presence.

Model	Covariables considered	DIC
1	Intercept	1446.7
2	Intercept + PCI + AR	1427.9
3	Intercept + PCI + AR + DOG	1410.6
4	Intercept + PCI + AR + CHK	1421.7
5	Intercept + PCI + AR + OTH	1428.7
6	Intercept + PCI + AR + DOG + CHK	1405.7
7	Intercept + PCI + AR + DOG + OTH	1411.2
8	Intercept + PCI + AR + CHK + OTH	1423.0
9	Intercept + PCI + AR + DOG + CHK + OTH	1406.9
10	Intercept + PCI + AR + DOG_CHK	1405.7
11	Intercept + PCI + AR + DOG_CHK + OTH	1406.9
12	Intercept + PCI + AR + ANIM	1407.9
13	Intercept +PCI + AR + N_AN	1408.6

Figure 2 presents the probabilities of finding premises with *Ae. aegypti* immature forms for models 2, where the presence of animals was not evaluated, and 10 (Table 3), according to different PCI values and the presence of dogs and chickens. Model 2 is represented in Figure 2 as TL (Tun-Lin abbreviation) and model 10 with the letters A, B, and C, respectively, representing the absence of dogs and chickens, the presence of only one or the other, and the presence of both. As the PCI increases, so do the probabilities of finding immature vector shapes in premises, regardless of the model and the situation considered. It is also observed that, for model 10-A, the probability of occurrence of the vector is lower compared to other situations, including the TL situation.

The presented results show that PCI values above 6 correspond to an increased risk of *Ae. aegypti* presence and that the inclusion in this index

Table 4
Posterior mean fixed effect and 95% credibility intervals (CIs) presented as odds ratios (ORs) for unadjusted models; adjusted model considering the premise condition index (PCI) and areas; and model considering the PCI, areas and presence of dogs and chickens (in all models spatial and area random effects were considered), Campinas, State of São Paulo, 2015-2016.

Covariable	Category	Posteriori average of fixed effect					
		Not adjusted values		Adjusted values of Model 2		Adjusted values of Model 10	
		OR	95%CI	OR	95%CI	OR	95%CI
Intercept			0.09	0.05-0.15	0.07	0.04-0.11	
Area	1	1		1		1	
	2	0.49	0.28-0.79	0.51	0.29-0.83	0.52	0.30-0.84
	3	0.91	0.55-1.43	0.82	0.49-1.30	0.75	0.45-1.1
	4	1.02	0.61-1.62	0.80	0.46-1.29	0.73	0.43-1.18
PCI	3	1		1		1	
	4	1.71	0.83-2.04	1.61	0.77-2.90	1.45	0.69-2.62
	5	1.34	0.85-2.04	1.32	0.83-2.03	1.21	0.75-1.85
	6	1.28	0.72-2.10	1.23	0.69-2.02	1.08	0.60-1.79
	7	2.55	1.54-4.02	2.42	1.43-3.88	2.13	1.25-3.44
	8	3.45	1.65-6.30	3.25	1.53-6.01	2.60	1.20-4.85
	9	6.56	0.72-22.46	6.37	0.70-21.88	5.94	0.63-20.66
Presence of Dogs and chickens	Neither	1				1	
	Dogs or chickens	2.00	1.47-2.69			1.93	1.40-2.60
	Both	5.38	2.61-9.63			4.55	2.17-8.28

information on the presence of animals could increase their discriminatory power. Considering model 10 (Table 3) as the most suitable for the construction of an extended PCI (PCIe) and the results presented in Table 4 and Figure 2, it is proposed to aggregate to each of the PCI values the letter A, representing premises without dogs and chickens; B, premises only with dogs or only with chickens; and C, premises with dogs and chickens.

4. Discussion

This study showed that the positivity of the premises for *Ae. Aegypti* increased according to PCI values and the presence of animals. It also showed that premises with a PCI ≥ 7 and with the presence of dogs and chickens are more likely to present the vector. These results match with those of other studies, reinforce the dose-response effect for PCI from 7 to 9 and the interaction between the presence of dogs and chickens in increasing the likelihood of encountering the vector. These results support the proposition of an expanded PCI that considers the presence of animals.

Importantly, both the model proposed by Tun-Lin et al., 1995 as the one presented in this paper are predictive, so that the considered variables do not necessarily have a causal relationship with the increased probability vector presence, but statistical association. This allows the use of these variables to predict the likelihood of *Ae. aegypti* breeding sites being found in a premise, which is interesting from the point of view of vector control. The association of the presence of dogs and chickens and an increased probability of the presence of the vector may be due to the existence of drinking fountains for these animals, the presence of an earth yard, which favour the presence of disposable containers, among other factors. We can also raise the hypothesis of these animals serving as a blood source for the vector.

It is noteworthy that the improvement of vector control tools also depends on the identification of the determining factors of vector infestation and not just those associated with it. Thus, it is also important to identify the characteristics of the premises that could be considered as causal factors of the infestation. Thus, testing the hypothesis that domestic animals may serve as a food source for the vector, as well as other characteristics of the premise that may be determinant for vector infestation, are issues that will be evaluated in future studies.

Andrighetti et al. (Andrighetti et al., 2009) showed that premises with a PCI above 6 accounted for more than 50% of pupal production. Peres et al. (Peres et al., 2013) compared, in three municipalities of Rio de Janeiro, the number of eggs found in oviposition traps in households with the respective PCI scores and observed a significant increase in the number of eggs in the traps with an increase in the PCI value. Still, in Rio de Janeiro, (Maciel-de-Freitas et al., 2008) showed that the spatial distribution of key premises and adult females of *Ae. aegypti* was often congruent, indicating that these key premises influence the infestation pattern observed in the study areas.

Nogueira et al. (Nogueira et al., 2005) in Botucatu showed the effectiveness of the PCI, where they found a high correlation between poorly maintained premises and the presence of *Ae. Aegypti* mosquitoes. Moreover, two other studies conducted in Mexico by Gomes et al. (Gomes et al., 2001) and Manrique-Saide et al. (Manrique-Saide et al., 2013) also found a positive relationship between increased PCI score and increased presence of *Ae. aegypti,* showing that the PCI can be a good parameter to identify key premises and consequently priority areas for vector control. The high positivity for *Ae. aegypti* in premises with dogs and chickens found in this study was also identified in a study by Fávaro et al. (Fávaro et al., 2013).

The positivity of the different socioeconomic evaluated areas showed no significant differences, except for area 2, with the second best level, which presented as protection against vector infestation. This reality may reflect the fact that the infestation depends less on the socioeconomic level than on the condition of each premise, since the vector has been present in the area for a long time. However, there is controversy on this issue, as some studies showed that there is a relationship between socioeconomic level and larval infestation (LaDeau et al., 2013; Azevedo et al., 2018; Whiteman et al., 2019) and others that did not find this relationship (Ferreira and Chiaravalloti Neto, 2007; Penso-Campos et al., 2018).

The increase in risk for the presence of the vector with the increase of the PCI and the presence of animals confirms that, for those premises that present a worse conservation condition and with the presence of animals, the chance of the presence of immature forms is higher. Then, this makes it plausible to incorporate the presence of dogs and chickens on the premises in the composition of an PCIe and to use it to identify key premises for vector control, for the conditions of the Brazilian reality.

The use of an PCIe together with the use of a GIS, similar to what was done in this study, allows the geographic visualization and area identification for occurrence of premises classified according to the PCIe, which allows direct control actions, both in the moments of infestation peaks and in advance of them. Nagpal et al. (Nagpal et al., 2016), in India, showed that an adequate intervention in seasons with low incidence or without dengue occurrence could reduce the vector density, with an impact on the reduction of cases in seasons favorable to the vector and the occurence of dengue.

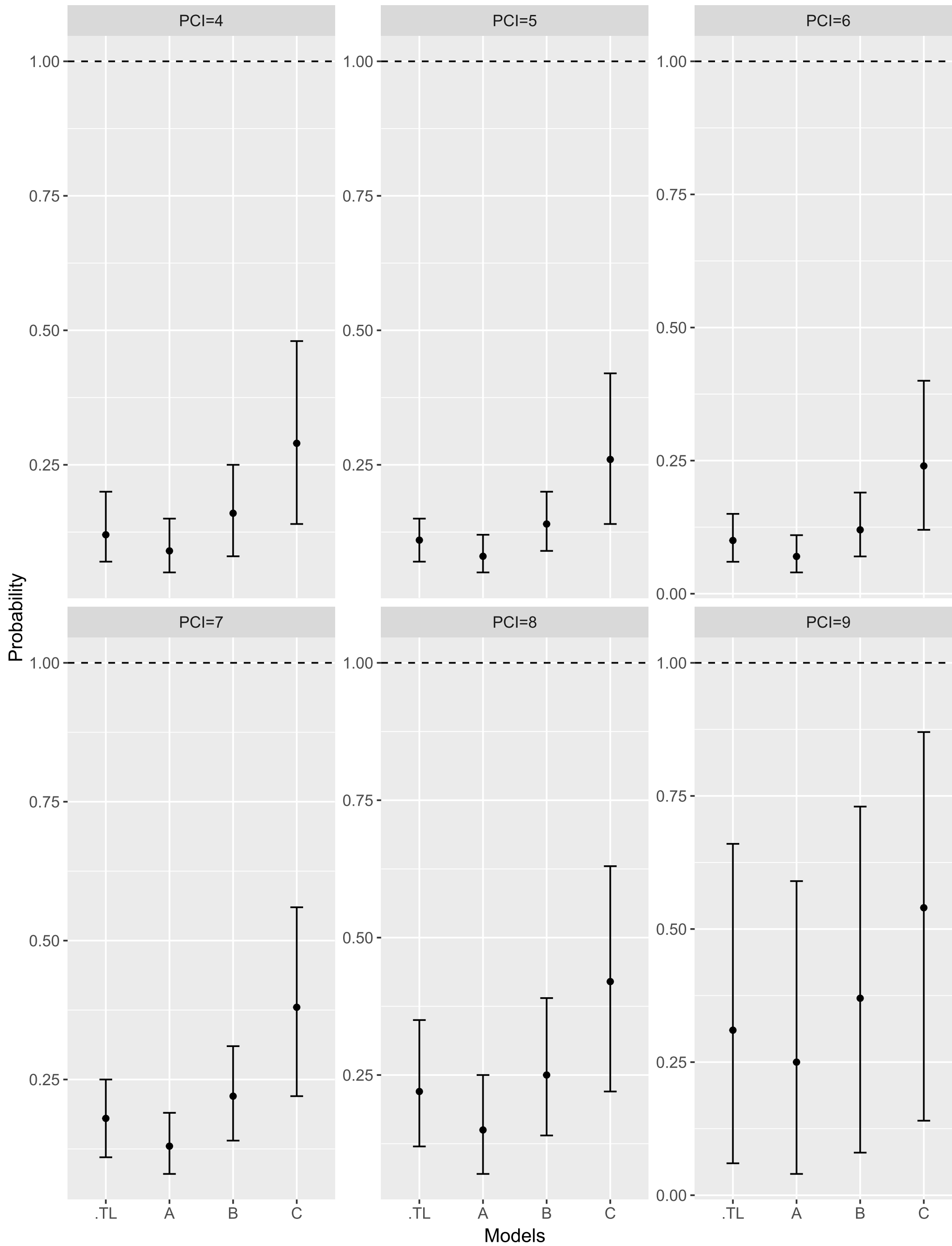

Figure 2. - Probabilities (with 95% CIs) of premises encountered with the presence of *Ae. aegypti* according to PCI values and different situations and models: TL - model 2 of Table 3; A - Model 10 of Table 3 and premises without the presence of dogs or chickens; B - Model 10 of Table 3 and premises with the presence of only dogs or only chickens; and C - Model 10 of Table 3 and premises with the presence of dogs and chickens in Campinas, State of São Paulo, Brazil, 2015-2016.

Direct consequences of the PCIe evaluation and use of a GIS in this study were the incorporation of this type of data collection system as a tool of the *Ae. aegypti* control program in the State of São Paulo and the inclusion of the PCIe registry of the premises visited in the program information system.

According to Marteis et al. (Marteis et al., 2013), key premises deserve priority in actions of vector control and constant vigilance, since they increase the chances of dengue transmission, especially in the period of the beginning of the rains where they tend to be more productive. The challenge is then to identify these premises that would allow the prioritization of areas where their concentration is high, which can optimize the resources available for vector control.

Similarly, LaCon et al. (LaCon et al., 2014) point out that focusing efforts on areas with historically high transmission levels within a city may be more effective than targeting the premises with larger *Ae. aegypti* foci. This is because, in spatial terms, the distribution within a well-defined area evidences a highly focal distribution of *Ae. aegypti* and hot spots are found in small common clusters of premises but are temporarily unstable. Thus, notwithstanding acting only on focal points, it would be more productive to define areas of intervention. Even if the same premises are not always positive over time, the use of the PCIe could be used to prioritize areas with a high concentration of premises with high values of this indicator for the development of vector control, optimizing the use of scarce resources available for this activity.

Marteis et al. (Marteis et al., 2013) also argue that risk indicators should not be based solely on indicators of vector infestation and should involve local criterion that expresses the epidemiological situation, considering the particularities of each region that may interfere with the dynamics of infestation. Thus, the use of the PCIe in conjunction with epidemiological indicators can contribute to the identification of priority areas for control and optimization of resource use.

However, for Getis et al. (Getis et al., 2003), even controlling key premises as a way to reduce *Ae. aegypti* populations cannot predict the effect that the elimination of breeding sites on key premises will have on the risk of human infection and disease occurrence. This reinforces the need to continue to carry out control actions that seek to reduce the population of *Ae. aegypti*, aiming to keep lower levels of infestation possible so that the risk of dengue and other arboviral infections decreases.

Although the present study and others (Andrighetti et al., 2009; Gomes et al., 2001; Maciel de Freitas et al., 2008; Manrique-Saide et al., 2013; Nogueira et al., 2005; Peres et al., 2013) show that the presence of key premises can be identified, the control and surveillance of *Ae. aegypti* needs to be implemented using new technologies that can guide the direction of actions to promote the reduction of the vector infestation to low levels that may imply the reduction of disease occurrence.

An important limitation in the use of the PCIe for area classification is the impossibility of classifying vertical areas, in addition to wastelands and areas with the presence of commercial properties. Also, for the PCIe to be an appropriate indicator, there is a need to standardize the procedures for premise classification, which is achieved through training and supervision of field staff.

The strengths of this study are obtaining the mobile geographic coordinates of the premises worked, the incorporation of data into a GIS and the modeling of data through latent Gaussian models in a Bayesian approach, which allowed the implementation of the analyses taking into account the spatial dependence of the positivity of the premises for *Ae. aegypti*.

Financial Support

This study was supported by São Paulo Research Foundation (FAPESP) with grant number 2015/06687-3 (for GLB). FCN is a CNPq (National Council for Scientific and Technological Development) Research Fellow.

Declaration of competing interests

None

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.actatropica.2020.105543.

References

Andrighetti, M.T.M., Galvani, K.C., da Graça Macoris, M.L., 2009. Evaluation of premise condition index in the context of Aedes aegypti control in Marília, São Paulo, Brazil. Dengue Bull 33, 167–175.

Azevedo, T.S.de, Bourke, B.P., Piovezan, R., Sallum, M.A.M., 2018. The influence of urban heat islands and socioeconomic factors on the spatial distribution of Aedes aegypti larval habitats. Geospatial Health 13. https://doi.org/10.4081/gh.2018.623.

Barbosa, G.L., Lage, M., de, O., Andrade, V.R., Gomes, A.H.A., Quintanilha, J.A., Chiaravalloti-Neto, F., 2019. Influence of strategic points in the dispersion of Aedes aegypti in infested areas. Rev. Saúde Pública 53, 29. https://doi.org/10.11606/S1518-8787.2019053000702.

Barrera, R., 2016. Recommendations for the surveillance of Aedes aegypti. Biomédica 36, 454–462. https://doi.org/10.7705/biomedica.v36i3.2892.

Bermudi, P.M.M., Kowalski, F., Menzato, M.M., da Ferreira, M.C., dos Passos, W.B.S., Oku, V.J.A., Kumow, A., Lucio, T.V.F.M., Lima-Camara, T.N., Urbinatti, P.R., Chiaravalloti Neto, F., Bermudi, P.M.M., Kowalski, F., Menzato, M.M., da Ferreira, M.C., dos Passos, W.B.S., Oku, V.J.A., Kumow, A., Lucio, T.V.F.M., Lima-Camara, T.N., Urbinatti, P.R., Chiaravalloti Neto, F., 2017. Criadouro de Aedes aegypti em reservatório subterrâneo de água da chuva: um alerta. Rev. Saúde Pública 51. https://doi.org/10.11606/s1518-8787.2017051000087.

Blangliardo, M., Cameletti, M., 2015. Spatial and Spatio-temporal Bayesian Models with R - INLA | Wiley [WWW Document]. Wiley.com. URLhttps://www.wiley.com/en-us/Spatial+and+Spatio+temporal+Bayesian+Models+with+R+INLA-p-9781118326558 (accessed 10.18.19).

Bortoloti, R., D'Agostino, R.G., 2012. Ações pelo controle reprodutivo e posse responsável de animais domésticos interpretadas à luz do conceito de metacontingência. Rev. Bras. Análise Comportamento 3. https://doi.org/10.18542/rebac.v3i1.821.

Chadee, D.D., 2004. Key premises, a guide to *Aedes aegypti* (Diptera: Culicidae) surveillance and control. Bull. Entomol. Res 94, 201–207. https://doi.org/10.1079/BER2004297.

Cressie, N., 1993. Statistics for Spatial Data. Wiley, New York.

Dowling, Z., Armbruster, P., LaDeau, S.L., DeCotiis, M., Mottley, J., Leisnham, P.T., 2013. Linking mosquito infestation to resident socioeconomic status, knowledge, and source reduction practices in suburban Washington, DC. EcoHealth 10, 36–47. https://doi.org/10.1007/s10393-013-0818-6.

Favaro, E.A., Dibo, M.R., Pereira, M., Chierotti, A.P., Rodrigues-Junior, A.L., Chiaravalloti-Neto, F., Favaro, E.A., Dibo, M.R., Pereira, M., Chierotti, A.P., Rodrigues-Junior, A.L., Chiaravalloti-Neto, F., 2013. *Aedes aegypti* entomological indices in an endemic area for dengue in Sao Paulo State, Brazil. Rev. Saúde Pública 47, 588–597. https://doi.org/10.1590/S0034-8910.2013047004506.

Ferreira, A.C., Chiaravalloti Neto, F., 2007. Infestation of an urban area by Aedes aegypti and relation with socioeconomic levels. Rev. Saúde Pública 41, 915–922.

Getis, A., Morrison, A.C., Gray, K., Scott, T.W., 2003. Characteristics of the spatial pattern of the dengue vector, Aedes aegypti, in Iquitos, Peru. Am. J. Trop. Med. Hyg 69, 494–505.

Gomes, F.E., Suárez, C.M.H., Cárdenas, R.C., 2001. Factores que modifican los índices larvarios de Aedes aegypti en Colima, México. Rev. Panam. Salud Pública 10, 6–12. https://doi.org/10.1590/S1020-49892001000700002.

Guzman, M.G., Halstead, S.B., Artsob, H., Buchy, P., Farrar, J., Gubler, D.J., Hunsperger, E., Kroeger, A., Margolis, H.S., Martínez, E., Nathan, M.B., Pelegrino, J.L., Simmons, C., Yoksan, S., Peeling, R.W., 2010. Dengue: a continuing global threat. Nat. Rev. Microbiol 8, S7–16. https://doi.org/10.1038/nrmicro2460.

LaCon, G., Morrison, A.C., Astete, H., Stoddard, S.T., Paz-Soldan, V.A., Elder, J.P., Halsey, E.S., Scott, T.W., Kitron, U., Prokopec, G.V., 2014. Shifting Patterns of *Aedes aegypti* Fine Scale Spatial Clustering in Iquitos, Peru. PLoS Negl. Trop. Dis. 8, e3038.

LaDeau, S.L., Leisnham, P.T., Biehler, D., Bodner, D., 2013. Higher Mosquito Production in Low-Income Neighborhoods of Baltimore and Washington, DC: Understanding Ecological Drivers and Mosquito-Borne Disease Risk in Temperate Cities. Int. J. Environ. Res. Public. Health 10, 1505–1526. https://doi.org/10.3390/ijerph10041505.

Lindgren, F., Rue, H., Lindström, J., 2011. An explicit link between Gaussian fields and Gaussian Markov random fields: the stochastic partial differential equation approach. J. R. Stat. Soc. Ser. B Stat. Methodol 73, 423–498. https://doi.org/10.1111/j.1467-9868.2011.00777.x.

Little, E., Biehler, D., Leisnham, P.T., Jordan, R., Wilson, S., LaDeau, S.L., 2017. Socio-Ecological Mechanisms Supporting High Densities of *Aedes albopictus (*Diptera: Culicidae) in Baltimore. MD. J. Med. Entomol 54, 1183–1192. https://doi.org/10.1093/jme/tjx103.

Lorenz, C., Chiaravalloti-Neto, F., Lage, M.O., Quintanilha, J.A., Parra, M.C., Dibo, M.R., Fávaro, E.A., Guirado, M.M., Nogueira, M.L., 2020. Remote sensing for risk mapping of *Aedes aegypti* infestations: Is this a practical task? Acta Trop 205, 105398. https://doi.org/10.1016/j.actatropica.2020.105398.

Maciel-de-Freitas, R., Peres, R.C., Souza-Santos, R., Lourenço-de-Oliveira, R., 2008. Occurrence, productivity and spatial distribution of key-premises in two dengue-endemic areas of Rio de Janeiro and their role in adult Aedes aegypti spatial infestation pattern. Trop. Med. Int. Health 13, 1488–1494. https://doi.org/10.1111/j.1365-3156.2008.02162.x.

Manrique-Saide, P., Davies, C.R., Coleman, P.G., Che-Mendoza, A., Dzul-Manzanilla, F., Barrera-Pérez, M., Hernández-Betancourt, S., Ayora-Talavera, G., Pinkus-Rendón, M., Burciaga-Zúñiga, P., Tejeda, G.S., Arredondo-Jiménez, J.I., 2013. The Risk of *Aedes aegypti* Breeding and Premises Condition in South Mexico. J. Am. Mosq. Control Assoc. 29, 337–345. https://doi.org/10.2987/13-6350.1.

Marteis, L.S., Steffler, L.M., de Araújo, K.C.G.M., dos Santos, R.L.C., 2013. Identificação e distribuição espacial de imóveis-chave de Aedes aegypti no bairro Porto Dantas, Aracaju, Sergipe, Brasil entre 2007 e 2008. Cad. Saúde Pública 29, 368–378. https://doi.org/10.1590/S0102-311x2013000200023.

Nagpal, B.N., Gupta, S.K., Shamim, A., Vikram, K., Srivastava, A., Tuli, N.R., Saxena, R., Singh, H., Singh, V.P., Bhagat, V.N., Yadav, N.K., Valecha, N., 2016. Control of Aedes aegypti Breeding: A Novel Intervention for Prevention and Control of Dengue in an Endemic Zone of Delhi, India. PLOS ONE 11, e0166768. https://doi.org/10.1371/journal.pone.0166768.

Nogueira, L.A., Gushi, L.T., Miranda, J.E., Madeira, N.G., Ribolla, P.E.M., 2005. Application of an alternative Aedes species (DIPTERA: CULICIDAE) surveillance method in Botucatu city, São Paulo, Brazil. Am. J. Trop. Med. Hyg 73, 309–311. https://doi.org/10.4269/ajtmh.2005.73.309.

Olliaro, P., Fouque, F., Kroeger, A., Bowman, L., Velayudhan, R., Santelli, A.C., Garcia, D., Ramm, R.S., Sulaiman, L.H., Tejeda, G.S., Morales, F.C., Gozzer, E., Garrido, C.B., Quang, L.C., Gutierrez, G., Yadon, Z.E., Runge-Ranzinger, S., 2018. Improved tools and strategies for the prevention and control of arboviral diseases: A research-to-policy forum. PLoS Negl. Trop. Dis. 12, e0005967. https://doi.org/10.1371/journal.pntd.0005967.

Penso-Campos, J.M., Fraga, E., Caldas, E., Sommer, J.A.P., Périco, E., 2018. Aspectos da paisagem e fatores socioeconômicos nos casos de dengue na cidade de Porto Alegre, RS (Landscape aspects and socioeconomic factors in the cases of Dengue in the city of Porto Alegre, RS. Rev. Bras. Geogr. Física 11, 1846–1858. https://doi.org/10.26848/rbgf.v11.5.p1846-1858.

Peres, R.C., Rego, R., Maciel-de-Freitas, R., 2013. The use of the Premise Condition Index (PCI) to Provide Guidelines for Aedes aegypti Surveys. J. Vector Ecol. 38, 190–192. https://doi.org/10.1111/j.1948-7134.2013.12027.x.

R: a language and environment for statistical computing [WWW Document], 2019. URL https://www.gbif.org/pt/tool/81287/r-a-language-and-environment-for-statistical-computing (accessed 10.18.19).

Rocha, C., 2017. Quais os desafios e restrições da única vacina contra a dengue [WWW Document]. Nexo J. URLhttps://www.nexojornal.com.br/expresso/2017/12/12/Quais-os-desafios-e-restri%C3%A7%C3%B5es-da-%C3%BAnica-vacina-contra-a-dengue (accessed 9.23.19).

Rue, H., Martino, S., Chopin, N., 2009. Approximate Bayesian inference for latent Gaussian models by using integrated nested Laplace approximations. J. R. Stat. Soc. Ser. B Stat. Methodol. 71, 319–392. https://doi.org/10.1111/j.1467-9868.2008.00700.x.

Schoendorfer, L.M.P., Germano, P.M.L., 2001. Interação homem-animal de estimação na cidade de São Paulo: o manejo inadequado e as conseqüências em saúde pública. Tese Doutorado Universiade de São Paulo.

Simpson, D.P., Rue, H., Martins, T.G., Riebler, A., Sørbye, S.H., 2015. Penalising model component complexity: A principled, practical approach to constructing priors. ArXiv14034630 StatME.

The R-INLA project [WWW Document], 2019 URL http://www.r-inla.org/ (accessed 10.22.19).

Tun-Lin, W., Kay, B.H., Barnes, A., 1995a. The Premise Condition Index: A Tool for Streamlining Surveys of Aedes aegypti. Am. J. Trop. Med. Hyg 53, 591–594. https://doi.org/10.4269/ajtmh.1995.53.591.

Tun-Lin, W., Kay, B.H., Barnes, A., 1995b. Understanding Productivity, A Key to Aedes aegypti Surveillance. Am. J. Trop. Med. Hyg 53, 595–601. https://doi.org/10.4269/ajtmh.1995.53.595.

Vannice, K.S., Durbin, A., Hombach, J., 2016. Status of vaccine research and development of vaccines for dengue. Vaccine. WHO Product Development for Vaccines Advisory Committee (PDVAC) Pipeline Analyses for 25 Pathogens 34, 2934–2938. https://doi.org/10.1016/j.vaccine.2015.12.073.

Whiteman, A., Gomez, C., Rovira, J., Chen, G., McMillan, W.O., Loaiza, J., 2019. Aedes Mosquito Infestation in Socioeconomically Contrasting Neighborhoods of Panama City. EcoHealth 16, 210–221. https://doi.org/10.1007/s10393-019-01417-3.