DOMESTIC Aedes aegypti BREEDING SITE SURVEILLANCE: LIMITATIONS OF REMOTE SENSING AS A PREDICTIVE SURVEILLANCE TOOL

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Abstract. This project tested aerial photography as a surveillance tool in identifying residential premises at high risk of Aedes aegypti breeding by extending the use of a recently developed, ground-based, rapid assessment technique, the modified Premise Condition Index (PCI). During 1995, we inspected 360 premises in Townsville, Australia for Ae. aegypti breeding, and PCI2 scores were recorded. The PCI2 values were also estimated from 1:3,000 color and infrared aerial photograph interpretation for the same premises. We found that shade levels can be accurately identified from both color and infrared images, and the PCI2 can be accurately identified from infrared photographs. Yard conditions, however, cannot be accurately identified from either aerial photograph type. The airborne PCI2 did not significantly correlate with breeding measures, and logistic regression further demonstrated that neither aerial photograph type allows the accurate prediction of Ae. aegypti breeding risk. Therefore, the ability of low-level aerial photography to enhance Ae. aegypti breeding site surveillance is at present limited, with ground surveillance remaining our most reliable tool for identifying the probability of Ae. aegypti breeding in the residential environment.

Dengue is now considered to be one of the most serious arboviral diseases, with two hundred million people at risk worldwide. Recent local outbreaks in 1981–1983, 1992–1993, and 1996–1997 indicate that dengue has also returned as a significant public health threat to northern Queensland, Australia. The major vector of dengue in Australia is the peridomestic mosquito Aedes aegypti, which uses a variety of artificial containers as larval habitat. Improved methods of breeding site surveillance are seen as important adjuncts to community-based source reduction campaigns to cost-effectively control Ae. aegypti populations.

Problems of expense and inaccuracy associated with premise larval surveys have been discussed elsewhere. In response to these problems, the Premise Condition Index (PCI) was developed as a rapid, cost-effective surveillance technique for identifying premises at high risk of breeding Ae. aegypti. The PCI is a simple index incorporating predictors of Ae. aegypti breeding (shade levels, yard tidiness, and house condition) that does not require the inspector to enter the premises. However, weaknesses of the PCI include the inability of the inspector to see into many rear yards, and the risk of inconsistent PCI scoring between different health inspectors.

Although aerial photography and satellite imagery have been used to efficiently identify and map mosquito breeding habitat, these involved large-scale wetland environments. As yet, this technology has not been applied to the identification of Ae. aegypti habitat due to the small size of individual breeding sites. Two components of the PCI (shade levels and yard tidiness) are a reliable indicator of Ae. aegypti breeding risk, and may potentially be identified as signatures through the use of low-level aerial photography. Aerial photography interpretation includes rear as well as front yards, and can involve a single worker, thus eliminating potential observer bias. Thus, high resolution aerial photography might be an effective tool for the rapid identification of Ae. aegypti breeding sites. In this study, we tested whether yard shade and tidiness could be recognized from 1:3,000 scale color infrared and normal color aerial photographs, and if so, whether this level of recognition was sufficient to create a possibly more cost-effective but still accurate rapid surveillance tool to identify potential Ae. aegypti breeding sites.

MATERIALS AND METHODS

Study site. Townsville is a coastal city in Queensland, Australia with a population of 125,000. Situated at a latitude of 19°16' S, it is subject to a dry tropical climate, with a short wet summer from December to March, usually with high rainfall. This is followed by a prolonged cooler dry period for the remainder of the year. Mean annual rainfall is 1,129 mm. Residential structures range in style throughout the study area from older high-set wooden houses to low-set units and individual residences built of brick or masonry block. A number of mosquito species are found in the Townsville region, but mosquito breeding in domestic containers is dominated by Ae. aegypti and the native Ae. notoscriptus (Tun-Lin W, unpublished data).

Aerial photograph acquisition. Aerial photography was obtained in April (normal color and color infrared) and November (color infrared only) 1995 along two transects in Townsville. These transects encompass much of the area that was most affected by the 1992–1993 epidemic and cover the range of socioeconomic groups, house ages and population densities in Townsville.

Both normal color and color infrared photography, which for convenience will be referred to as color and infrared, respectively, were used to ascertain which allowed the best identification of PCI components. The color photography has a spectral range between 0.4 and 0.7 μm, closely represents the scene as seen by the human eye, and provides the widest tonal range. The false color infrared photography has a spectral range between 0.5 to 0.9 μm and can be used to identify standing pools of water, which because of their high absorption of near infrared radiation, appear conspicuously black. Photographs were taken by a single-lens frame Wild RC8 Certified Survey Camera (Leica AG, St. Gallen, Switzerland), with a focal length of 152 mm (6") and 230 × 230 mm format. The color and infrared photography used Kodak
2445 and Kodak 2443 film (Eastman Kodak, Rochester, NY), respectively.

Aerial photograph interpretation. The measurement of the degree of canopy closure at spatial scales greater than 1:5,000 was accomplished using transparent dot grid overlays. We found that in an urban area, with its high contrast, a grid square more easily allowed shade estimation. Therefore, once identified on the respective image, the premises in question was overlain by a grid square transparency with a resolution of 1 mm. Grid squares were categorized as follows: 1) areas covered by trees or shrubbery; 2) grass and bare ground, i.e., areas not covered by tree canopy or shrubbery; and 3) squares corresponding to the roof of premises.

A preliminary training set of 14 premises were categorized as above and compared with shade levels estimated during the ground surveys. Percentage canopy cover was then estimated and a percentage cover < 25% was given a score of 1, a cover > 25% but < 50% was given a score of 2, and a percentage > 50% was given a score of 3. Eleven of the 14 training premises corresponded to the ground survey score, which provides an accuracy of 79%.

The yard condition was also estimated for each ground surveyed premises where covered by the aerial photographs, and given a score from 1 to 3. This element of the PCI was a more subjective assessment, whereby unusual shapes, shades, or color suggested rubbish. Thus, the estimation of yard condition incorporated the contextual knowledge of the interpreter. Where clutter was evident, although little of the yard was visible, the level of visible clutter was assumed to be the same as that under the vegetation canopy. The shade and yard scores were then added to create the PCI, (an overall score out of 6).

Ground survey. The PCI components and Ae. aegypti breeding were recorded for a total of 360 premises. Yard condition and shade were estimated from the front fence and indexed as follows: Yard condition: 1) tidy yard, e.g. no rubbish evident, well-maintained gardens; 2) moderately tidy yard; 3) untidy yard and/or a mess; and Shade: 1) very little or no shade (< 25%); 2) some shade (25–50%); 3) shady (> 50%), e.g., large trees, lots of shrubbery.

Larval inspections were also performed around the exterior of each premises. All Ae. aegypti-positive breeding container types, the location of each positive container, and the numbers of fourth instar larvae and pupae in each container were recorded.

The 1:3,000 scale photographs cover a ground swath of approximately 660 m (330 m each side of the nadir line). To allow for possible deviation from the expected transects due to tilt or other consequences of air turbulence such as crab or drift, premises to be ground surveyed were deliberately confined to within 180 m each side of the expected nadir line, approximately half the photograph’s width.

Not all ground surveyed premises were covered by the aerial photography. Unexpected gaps, especially among the color photographs, meant that although 360 premises were ground surveyed, only 160 and 348 premises were covered in the color and infrared photographs, respectively. Thus, a further 101 premises were ground surveyed for PCI components on August 12, 1995 to increase the sample size for comparing the ground surveys with aerial photographs.

Statistical analyses. Paired comparison tests were used to compare the PCI (yard and shade) derived from each of the two aerial types of aerial photography with the results from ground surveys. The PCI was then broken down into its two components for comparison between ground and each of the two aerial surveys. The non-normal frequency distributions of the small range of PCI values required the use of nonparametric Wilcoxon sign-rank tests. Spearman’s rank was used to correlate the color- and infrared photography–derived PCI (yard and shade) values against two measures of Ae. aegypti breeding: 1) the proportion of premises that are positive for Ae. aegypti breeding and 2) the mean number of positive breeding containers per premises. The yard, shade, and PCI (color and infrared) were also tested as explanatory models for breeding prevalence using logistic regression. The increase in explanatory power of the model from that containing only the constant was tested by the chi-square test.

RESULTS

Aerial recognition of PCI components. Only the infrared photography–estimated shade and PCI, and the color photography–estimated shade were not statistically different from the corresponding ground estimates (two-tailed P = 0.2850, 0.1726, and 0.1282, respectively). Thus, the infrared photography overall better reflected the ground survey than did the color photography. The yard condition estimates from both the color and infrared photograph were negatively skewed, i.e., both types of aerial photography resulted in a greater proportion of underscored rather than overscored estimates (infrared and color PCI estimates were lower than ground estimates in 24% and 35% of cases, respectively, and higher in 20% and 16% of cases). Shade level estimates from both the color and infrared photography resulted in the highest level of agreement with ground estimates (75.5% and 77.4%, respectively). The overall PCI (yard condition and shade level) estimates from the color images were less accurate than those from the infrared images (49% versus 56% matched pairs, respectively).

The aerial PCI as a predictor of Ae. aegypti breeding. Neither infrared nor color photography estimated PCI estimates correlated significantly with either the proportion of positive premises or the mean number of positive containers per premises (Tables 1 and 2). For the infrared PCI, r = 0.6, degrees of freedom (df) = 4 and P = 0.4 for both mea-
sures of breeding prevalence. For the color PCI\(_2\), \(r = 0.6325\), df = 4, \(P = 0.368\) and \(r = 0.4\), df = 4 and \(P = 0.6\) for the above measures of breeding prevalence, respectively.

Similarly, neither the infrared nor the color PCI\(_2\) improved the logistic model explaining breeding prevalence (\(\chi^2 = 1.083\), df = 1, \(P = 0.2980\), and \(\chi^2 = 0.270\), df = 1, \(P = 0.7772\), respectively). Therefore, unlike the ground-generated PCI\(_1\) and PCI\(_2\), neither aerial photography generated PCI\(_1\) significantly improves the prediction of the probability of \(Ae.\ aegypti\) breeding in a premises.

The infrared and color shade estimates did not improve the logistic model (\(\chi^2 = 1.308\), df = 1, \(P = 0.2527\), and \(\chi^2 = 0.270\), df = 1, \(P = 0.6035\), respectively). Likewise, yard estimates from each image type also failed to explain breeding prevalence (\(\chi^2 = 0.032\), df = 1, \(P = 0.8581\), and \(\chi^2 = 0.127\), df = 1, \(P = 0.7221\)).

**DISCUSSION**

We were able to accurately estimate shade levels from both the color and infrared images. However, more accurate identification of the PCI\(_1\) values was achieved using the infrared images which allowed more precise differentiation between vegetation structural types such as trees, shrubs, and lawn.

Our inability to identify yard condition was, to some degree, due to the spatial resolution of the photography, which failed to delineate small items such as ice cream containers. A second problem was the vegetation canopy and the shade it produced, which hid much of the yard clutter. This factor was reflected in the complete lack of aerial photography PCI\(_1\) scores of 6. Relief displacement, whereby the angle at which objects can be seen towards the edge of photographs is not vertical,\(^{10}\) was also found to obscure some areas of clutter adjacent to larger structures such as houses or garages. Furthermore, the color images were, due to turbulence problems, obtained at 8:30 AM as compared to 10:00 AM for the infrared photographs. This resulted in longer shadows, and therefore larger areas of yards remaining invisible in the color images.

The failure of aerial photography as a predictor of \(Ae.\ aegypti\) breeding prevalence and breeding container abundance was due primarily to the inability to accurately identify the yard conditions. In other words, the conservative estimates of yard conditions, when added to shade estimates, resulted in fewer matched PCI\(_2\) pairs than matching shade pairs. Even shade level estimates, which in both the color and infrared photography resulted in the highest level of agreement with ground estimates, is unsuitable as an indicator of breeding likelihood.

Since there was no statistical difference between our ground and infrared estimated PCI\(_2\), we believe that aerial surveillance for \(Ae.\ aegypti\) breeding site identification has some potential. However, the difficulty in identifying yard condition is a particular problem. To improve the aerial surveil- lance of yard condition components, one could seek either a larger scale image and/or an image taken closer to midday, which would reduce shadowing. However, this higher resolution would increase costs. In addition, aerial photography taken later in the day may be subject to both greater cloud cover and increased turbulence.

Additionally, multispectral and microwave technologies have yet to be applied to this task, which may facilitate improved recognition of PCI components. At present, however, ground surveillance remains our most reliable tool for identifying the probability of \(Ae.\ aegypti\) breeding in the residential environment.

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**REFERENCES**


**TABLE 2**

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<th>PCI(_1) (color)</th>
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