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Comparison of Different Mosquito Traps for Zoonotic Arbovirus Vectors in Papua New Guinea

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Abstract. Vector surveillance is important to control mosquito-borne diseases. We compared the efficacies of three mosquito-trapping devices: the CDC light trap with incandescent light (CDC_I), the CDC light trap with ultraviolet light (CDC_UV), and the Biogents-sentinel (BG) trap, to identify a suitable and cost-effective surveillance tool for key vectors of neglected zoonotic arboviral diseases in Papua New Guinea (PNG). Of 13,788 female mosquitoes, CDC_I caught 7.9%, BG caught 14.5%, and CDC_UV caught 77.6%. *Culex* was the most predominant genus caught in all the traps. Centers for Disease Control light trap with ultraviolet light trap captured the highest abundance, highest species richness of mosquitoes and exhibited the highest overall *Culex* mosquito capture rates compared with BG and CDC_I. This study represents the first assessment of trapping devices for zoonotic arbovirus vectors in PNG. We recommend the CDC _UV trap for future monitoring and surveillance of infectious arboviral vector programs in PNG.

Mosquitoes are important vectors of zoonotic viral diseases. In Papua New Guinea (PNG), the flaviviruses, Japanese encephalitis virus, and Murray Valley encephalitis virus have been isolated from *Culex sitiens* subgroup mosquitoes,[1] while there has been serological evidence for the *Culex*-vectored West Nile–Kunjin virus.[2] The alphaviruses Ross River virus (RRV) and Barmah Forest virus have been isolated from *Anopheles farauti* (RRV)[1] and a single human case of Barmah Forest infection[3]; both viruses are also known to be vectored by several *Aedes* and *Culex* species found in PNG.[1,4,5] However, due to limited vector surveillance activities carried out in PNG for zoonotic arboviruses, the extent of their circulation and the range of vector mosquito species are poorly understood.

Vector control is the principal method available, and sometimes the only effective way, to reduce transmission of vector-borne infectious diseases.[6] Effective vector control requires sensitive and efficient surveillance tools to monitor the species composition and dynamics of local mosquito populations. Many techniques can be used to collect mosquitoes including aspiration, spray sheet collections, sweep net collections, human landing catches (HLCs), and the deployment of a variety of mechanical trapping devices. In PNG, HLCs have been shown to be the only effective method to collect larger numbers of mosquitoes that are anthropophilic,[7] whereas other important disease vectors such as *Aedes* spp. and *Culex* spp. can be efficiently collected using mosquito traps.

Numerous trapping devices are available for capturing mosquitoes, but trapping success may vary depending on species-specific cues (e.g., visual, olfactory, carbon dioxide)[8] and sampling conditions.[9] One of the simplest and most widely used trap types for capturing mosquitoes is the CDC light trap.[10] Centers for Disease Control light traps can be used with only light as attractant, but can also be supplemented with other mosquito attractants (such as CO_2 or octenol) to enhance mosquito collection.[11,12] Previous studies conducted elsewhere have evaluated trapping devices in many environments.[9,13–19] Some studies showed that CDC light traps are more effective in capturing *Anopheles* and *Culex* than *Aedes* mosquitoes.[9,18,20] Biogents-sentinel (BG) trap, which uses both visual and olfactory cues, was designed to capture *Aedes albopictus*.[21] Previous reports comparing BG to light traps have shown that BG traps with or without lures are more effective at capturing *Aedes* than the light traps.[13–15] Light emitting diodes (LEDs) with ultraviolet (UV) light are also increasingly being assessed for capturing mosquitoes and previous studies showed that CDC light traps with UV light have higher trapping efficacies than those with incandescent light.[17,22,23] Different trap types may yield higher capture rates for different mosquito species based on their visual attractant. So far, there has been no published work on the evaluation of different traps for improved capture of field populations of mosquitoes in PNG.

In this study, we evaluated the effectiveness of three types of traps to capture mosquito species responsible for transmission of zoonotic arboviruses in commercial farms in PNG. The study was conducted at eight agricultural farming sites in Central and Morobe provinces, from November to December 2019 and September to October 2020, respectively (Figure 1). The annual average temperatures for Central and Morobe provinces are 30°C and 26.4°C, respectively, and rainfall is 1,150 mm and 4,313 mm, respectively. This climate is ideal for the development and reproduction of vector mosquitoes. The farms were selected in consultation with the PNG National Agriculture Quarantine Inspection Authority (NAQIA), which undertakes routine surveillance for livestock diseases but not mosquito surveillance. In each province, four farms (two piggeries and two chicken farms) were selected and traps were placed adjacent to livestock pens.

Three different traps were compared: BG trap (BioGents, Regensburg, Germany), miniature CDC light trap with incandescent light (CDC_I), and miniature CDC light trap with ultraviolet light (CDC_UV; BioQuip Products, Rancho Dominguez, CA), all without lures. Traps were placed for two periods of 5 days per farm. Specifically, for the first 5-day period, five CDC_I traps and one BG trap were placed in one animal shelter, while five CDC_UV traps and one BG trap were placed in another animal shelter. In the second 5-day period, CDC_I and CDC_UV traps were rotated. Centers for Disease Control light traps were hung on animal housing 2 meters above the ground, while BGS traps were placed on the ground. Every 24 hours, mosquitoes were collected and

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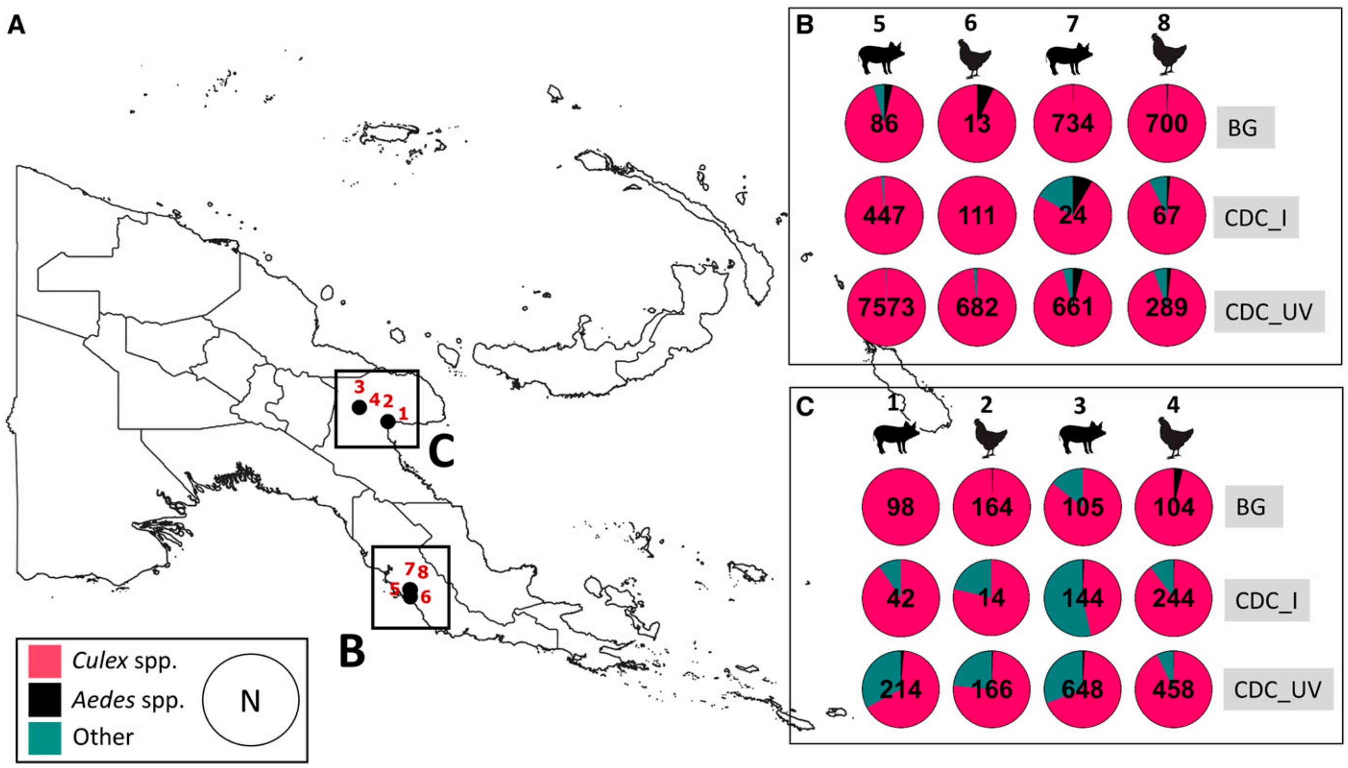

FIGURE 1. Summary of mosquito collections. Panel A shows the collection locations in the two areas of Papua New Guinea (PNG), namely Central Province (inset B) and Morobe Province (inset C). In each location, traps were set up in two pig farms and two chicken farms. Panels B and C show mosquito distribution and abundance in per collection site (farms labeled 1–8) and trap type (BG = Biogents-sentinel trap, CDC_I = CDC miniature light trap with incandescent light, CDC_UV = CDC miniature light trap with ultraviolet light). Each pie chart represents the mosquito distribution in one collection site and for one trap type. The numbers inscribed within the pie charts denote the overall number of mosquitoes collected. This figure appears in color at www.ajtmh.org.

transported to the laboratory for species identification. Mosquitoes were placed on white filter paper in a Petri dish, and the species identified morphologically under a stereo microscope (Zeiss, Jena, Germany) using taxonomic keys.[24] Trapping periods were calculated as the number of traps multiplied by the number of 24-hour-trap day for each trap. Altogether, there were 960 trap periods (160 for BG, two traps operated over 10 days $\times$ 8 farms; 400 for CDC_I: 5 traps operated over 10 days $\times$ 8 farms; and 400 for CDC_UV).

Because of the lack of normality of the data and large standard deviations, nonparametric tests were used to analyze mosquito densities. Trapping rates (number of mosquitoes collected per trap per day) were calculated. Differences in mosquito trapping rates among the three trap types were assessed using independent samples median tests, followed by Bonferroni correction for multiple tests. Statistical analysis was performed using IBM SPSS Statistics for Windows Version 27.0 (IBM Corp., Armonk, NY).

Nine hundred and sixty 24-hour trapping periods yielded 13,788 female mosquitoes of which 13,041 (95.6%) were identified to species level. Mosquito species captured included *Ae. albopictus*, *Ae. aegypti*, *An. bancrofti*, *An. farauti*, *An. koliensis*, *An. longirostris*, *An. punctulatus* s.s., *Cx. annulirostris*, *Cx. gelidus*, *Cx. Quinquefasciatus*, and *Cx. sitiens.* Two genera *Armigeres* and *Mansonia* were also captured. Mosquitoes belonging to the *Culex* genus were the most abundant caught in all traps and at all study sites, comprising 95.4% of the total catch (Figure 1). The predominant species captured by BG traps was *Cx. quinquefasciatus* (96.7%), whereas for the other two traps, it was *Cx. gelidus* (CDC_I: 54.0%; CDC_UV: 80.4%). Mosquito capture data are provided in Supplemental Table 1. Centers for Disease Control light trap with ultraviolet light traps caught all of the 11 species identified in the present study, followed by CDC_I (eight species, 72.7%) and BG trap (seven species, 63.6%). All trap types caught the four *Culex* species identified (Figure 2). Biogents-sentinel traps captured both *Aedes* species and only one *Anopheles* species, whereas CDC_I traps caught one *Aedes* and three *Anopheles* species (Figure 2).

Independent samples median tests showed that there were statistically significant differences in median trapping rates across the trap types (all sites combined) for the following four species: *Cx. annulirostris:* $X^2(2) = 14.434$, $P = 0.001$; *Cx. gelidus:* $X^2(2) = 9.399$, $P = 0.009$; *Cx. quinquefasciatus:* $X^2(2) = 9.000$, $P = 0.011$; and *Cx. sitiens:* $X^2(2) = 7.000$, $P = 0.030$. There was no evidence of a significant difference for the other species, which may also be a result of the low number of mosquitoes captured for some species. In addition, the low number of anthropophilic mosquitoes observed could be due to the sampling location, which is animal houses, where human exposure is minimal.

Further pairwise comparisons of the median test and *post-hoc* test result based on Bonferroni correction are presented in Figure 3. Among the traps compared, CDC_UV exhibited the highest efficacy for trapping *Cx. annulirostris*, *Cx.*

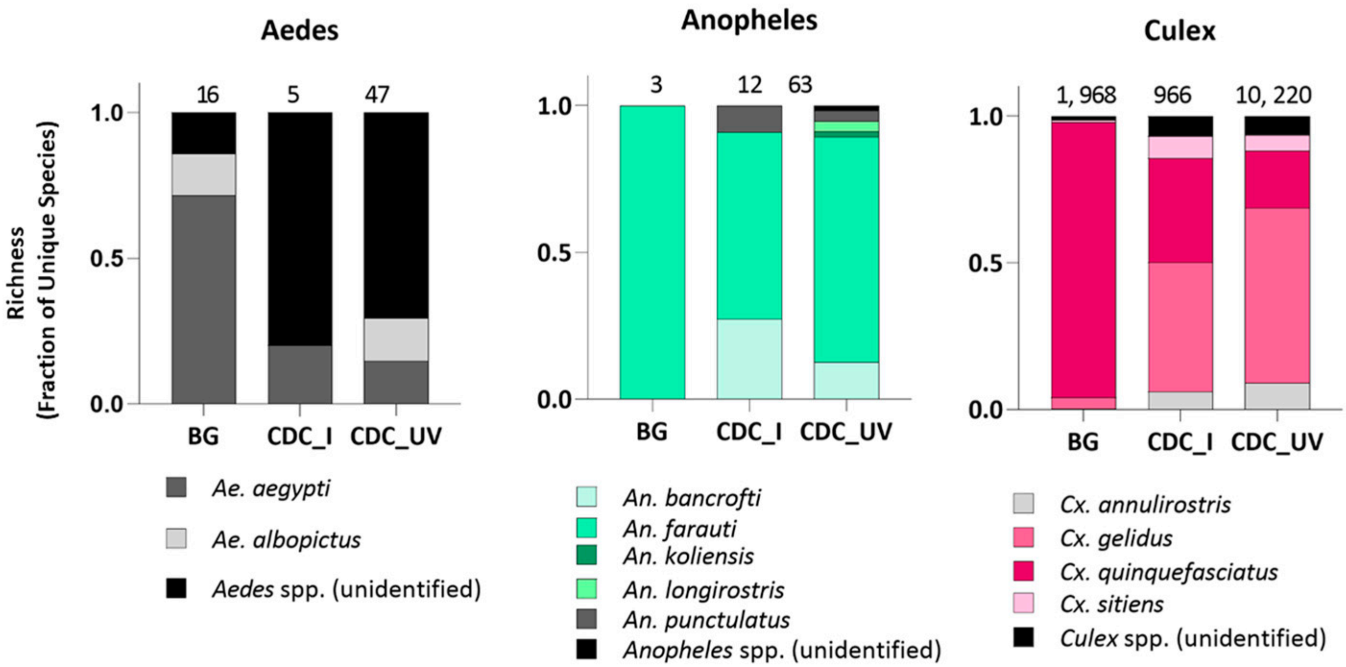

FIGURE 2. Species of mosquitoes caught among the three trapping devices. Numbers atop each column represent total number of mosquitoes caught by that trap. BG = Biogents-sentinel (BG) trap, CDC_I = CDC light trap with incandescent light, and CDC_UV = CDC light trap with ultraviolet light. This figure appears in color at www.ajtmh.org.

gelidus, and *Cx. sitiens*, with median trapping rates of 1.12, 4.62, and 0.54 per trap day, respectively. The BG trap showed the lowest overall median trapping rates, which was zero for the same three species ($X^2 = 9.000$, $P = 0.008$, in all cases). However, BG traps were significantly more effective than CDC_I at capturing *Cx. quinquefasciatus* ($X^2 = 9.000$, $P = 0.008$), with a median trapping rate of 8.85 per trap day compared with 0.06 per trap per day for the CDC_I trap. These univariate analyses were well supported by a multivariate negative binomial model that accounted for province and farm type as covariates (Supplemental Table 2 and Supplemental Figure 1).

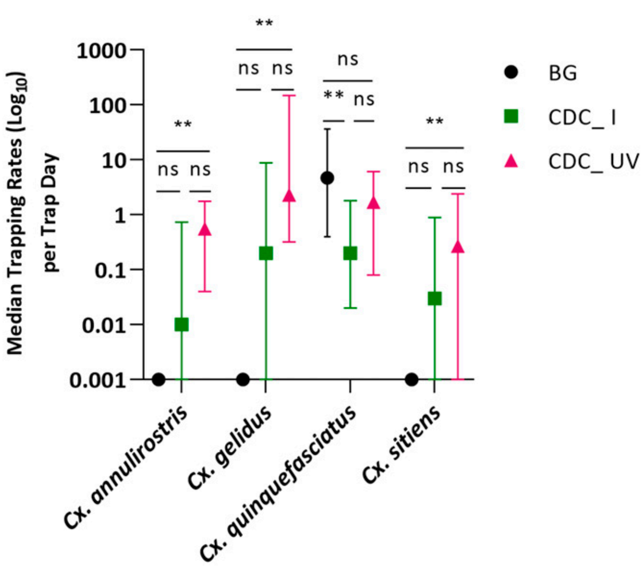

FIGURE 3. Median log_{10} Trapping Rates (number of mosquitoes caught per trapping day) of the three trapping devices. BG = Biogents-sentinel (BG) trap, CDC_I = CDC light trap with incandescent light, and CDC_UV = CDC light trap with ultraviolet light. Error bars represent 95% CIs. Capture rates were compared using independent samples median test with Bonferroni correction. Statistical significance is indicated by * symbols: with ** denoting a P value of $\leq$ 0.01 and ns = nonsignificant. This figure appears in color at www.ajtmh.org.

Various commercial trapping devices are available for mosquito monitoring or surveillance. This study compared traps for capturing vectors relevant for the transmission of zoonotic arboviruses in commercial farming environments in PNG. We showed that the CDC_UV captured the highest number of mosquitoes and the most species as compared with BG traps and CDC light traps with incandescent light. These differences are based on comparisons in 960 trap nights across eight farms. Similar results between UV and incandescent light traps have also been reported from studies conducted in Thailand, China, and Tanzania, in which traps were placed inside homes.[17,22,23] There are fewer published studies comparing the efficacies of BG traps and CDC_UV traps. For instance, a recent study in Thailand has shown that CDC light trap augmented with UV performed better than BG trap for capturing *Anopheles* sp. in the villages.[18]

While some previous studies[25–27] have used BG and CDC traps in farming environments, we could not identify published studies that compared capture rates using the same trap types we used. For example, in China, Hou et al. (2021) compared CDC_UV and BG-Mosquitaire trap baited with lures in five different biotopes including a pig shelter. The pig shelter was the only place where CDC_UV outperformed BG-Mosquitaire in capturing the highest number of mosquitoes.[25] Species wise, CDC_UV caught significantly more *Cx. tritaeniorhynchus* whereas BG-Mosquitaire trap caught more *Ae. albopictus*.[25] In South Africa, Johnson et al. (2020) used

CO_2-baited traps (CDC and Mosquito tent trap) in horse farms but they did not specifically compare the two trap types.[26] *Culex theileri*, *Cx. univittatus*, and *Cx. pipiens sensu lato* were the most dominant species caught.[26] In Europe, Möhlmann et al. (2017) used two CO_2-baited traps (BG and Mosquito Magnet Liberty Plus [MMLP]) to capture mosquitoes in various habitats including dairy farms. Mosquito Magnet Liberty Plus trapped the largest number of mosquitoes in Sweden and Italy, whereas the BG trapped most mosquitoes in the Netherlands and the most dominant species caught were *An. maculipennis* for Sweden and *Cx. pipiens* for the Netherlands and Italy.[27] Other studies used only one trap type in animal farms; CO_2-baited CDC light traps in dairy farms in Nigeria where *Cx. quinquefasciatus* was the most abundant species caught[28] and CO_2-baited MMLP trap in horse farms in Belgium where the most abundant species caught was *Coquillettidia richiardii*.[29] Although the traps used in other studies were different to ours, our findings are similar in that the abundant genus caught was mostly *Culex* in all the studied animal farms.

Limitations of this study include the small number of farms and provinces. While a balanced trapping study design was used for CDC_UV and CDC_I, the BG traps were used as "controls" with one BG trap in each location run concurrently with the CDC_I and CDC_UV traps. This may have affected the capture rates and species richness observed, especially in the BG traps as it could be that mosquitoes were drawn away by nearby CDC_I or CDC_UV traps. However, our results are well aligned with recent BG trapping observations from Madang province in PNG.[30]

Based on these findings, we recommend CDC_UV traps for future research and programmatic monitoring studies of *Culex* species relevant for zoonotic arbovirus transmission in PNG.

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Note: Supplemental tables and figure appear at www.ajtmh.org.

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