The Centres for Disease Control Light Trap (CDC LT) and The Human Decoy Trap (HDT) Compared to The Human Landing Catch (HLC) for Measuring Anopheles Biting in Rural Tanzania

Isaac Haggai Namango (isaac.namango@swisstph.ch)
Swiss Tropical and Public Health Institute: Schweizerisches Tropen- und Public Health-Institut  https://orcid.org/0000-0002-7869-1222

Carly Marshall
Ifakara Health Institute

Adam Saddler
Ifakara Health Institute

Amanda Ross
Swiss Tropical and Public Health Institute: Schweizerisches Tropen- und Public Health-Institut

David Kaftan
Ifakara Health Institute

Frank Tenywa
Ifakara Health Institute

Noely Makungwa
Ifakara Health Institute

Olukayode Odufuwa
Ifakara Health Institute

Godfrey Ligema
Ifakara Health Institute

Hassan Ngonyani
Ifakara Health Institute

Isaya Matanila
Ifakara Health Institute

Jameel Bhamal
Innovative Vector Control Consortium

Jason Moore
Ifakara Health Institute

Sarah Moore
Ifakara Health Institute

Manuel Hetzel
Swiss Tropical and Public Health Institute: Schweizerisches Tropen- und Public Health-Institut

Research

Keywords: CDC LT, Afrotropical mosquitoes, entomological surveys, HDT

Posted Date: December 28th, 2021

DOI: https://doi.org/10.21203/rs.3.rs-1169022/v1

License: This work is licensed under a Creative Commons Attribution 4.0 International License. Read Full License
Abstract

Background

The intensity of vector mosquito biting is an important measure for malaria epidemiology and control. The human landing catch (HLC) is an effective entomological surveillance tool, but is labour-intensive, expensive and raises safety issues. The Centers for Disease Control light trap (CDC LT) and the human decay trap (HDT) are less costly and exposure-free alternatives. This study compared the CDC LT and HDT against the HLC for measuring Anopheles (An.) biting in rural Tanzania and assessed their suitability as HLC proxies.

Methods

Indoor mosquito surveys using HLC and CDC LT and outdoor surveys using HLC and HDT were conducted in 2017 and in 2019 in Ulanga, Tanzania in 19 villages, with one trap per house per night. Species composition, sporozoite rates and the numbers of mosquitoes caught by different trap types were compared. Aggregating the data by village and month, the Bland-Altman approach was used to assess agreement.

Results

Overall, 66,807 Anopheles funestus and 14,606 An. arabiensis adult females were caught from 6,013 CDC LT, 339 indoor HLC, 136 HDT and 195 outdoor HLC collections. Overall, the CDC LT caught fewer malaria vectors than indoor HLC: An. arabiensis (Adjusted rate ratio (Adj.RR) =0.35 (95% confidence interval (CI):0.27-0.46)) and An. funestus (Adj.RR=0.63(95%CI:0.51-0.79)). HDT caught fewer malaria vectors than outdoor HLC: An. arabiensis (Adj.RR=0.04(95%CI:0.01-0.14)) and An. funestus (Adj.RR=0.10(95%CI:0.07-0.15)). The bias and variability of the ratios of geometric mean mosquitoes caught by CDC LT and HDT relative to HLC collections for the same village-month were dependent on mosquito densities. The relative efficacies of both CDC LT and HDT declined with mosquito abundance. The variability in the ratios was substantial for low HLC counts and decreased as mosquito abundance increased.CDCLT caught a higher proportion of infected An. arabiensis and An. funestus than HLC, and HDT caught no infected mosquitoes.

Conclusions

If caution is taken in appreciation of its limitations, the CDC LT is suitable for use in routine entomological surveys and may be preferable for measuring sporozoite rates for Afrotropical mosquitoes. Use of HLC is useful to estimate human exposure to mosquitoes for estimating Entomological Inoculation Rate (EIR). The present design of the HDT is not amenable for use to conduct large-scale entomological surveys.

Background

Measuring Anopheles biting is a core part of the monitoring and surveillance of malaria vectors. The Anopheles females, responsible for the transmission of malaria, bite humans to obtain a blood meal needed for egg production. The proportion of biting mosquitoes that are infected is essential to quantify the entomological inoculation rate (EIR), the most reliable vector-based index for estimating infection transmission intensity and the impact of vector control interventions. Anopheles biting is assessed by collecting host-seeking mosquitoes around areas occupied by humans over regular time intervals throughout the night [1–7].

The human landing catch (HLC), is considered the gold-standard method to assess human exposure to Anopheles biting [8, 9]. Individuals recruited to perform HLC (catchers), collect mosquitoes attracted to and alighting on their lower limbs using an aspiration tube before the mosquitoes attempt to bite, ideally over hourly intervals all night (Figure 1A). The number of mosquitoes collected by the HLC is presumed to represent the actual intensities and patterns of malaria vector biting. The biting rates and EIRs assessed by the HLC are the most reliable for malaria surveillance and are used as a reference for standardizing other methods [6, 8–11].

HLC surveys, however, have important limitations that restrict use. Although it has been demonstrated that observing proper HLC protocol minimises the risk of malaria infection among catchers [12, 13], use of human baits to catch mosquitoes that have the potential to transmit malaria creates ethical and safety concerns, particularly with the emergence of antimalarial drug-resistance [12, 14], or in areas with active arbovirus circulation. HLCs are also labour-intensive, cumbersome and incur considerable costs to run on a large scale [15]. Variations in the alertness and skill of catchers requires careful supervision, and differences in attractiveness to mosquitoes make HLC surveys hard to standardize [8, 16, 17]. As such, the HLC has been found unsuitable for the extensive and continuous operational exercise of malaria vector monitoring and surveillance for disease control [18]. Accordingly, the World Health Organization (WHO) encourages research and use of alternative mosquito traps with only sparing use of HLC for purposes such as calibrating new tools [19, 20].

Several attempts have been made to find options that measure biting rates but do not rely heavily on human effort or involve exposure to infection [8]. The target profile for anopheline collection methods to be used as HLC surrogates comprise traps that actively lure host-seeking females by use of host-based cues, usually a combination of olfactory, visual and thermal cues and their selection depends on the effectiveness to replicate efficiency of human attraction [8, 9, 21]. The number of mosquitoes caught by a trap should be comparable via a reliable algorithm to those caught by the HLC [22]. Entomological monitoring for disease control further requires traps that are easily scalable.

Developed initially for sampling agricultural pests, light traps have found common use for collecting malaria vectors after Odetoynbo first demonstrated their efficacy against host-seeking anophelines [23]. The common battery-powered CDC LT, shown in Figure 1 (B and C), is usually used alongside untreated bed nets to collect mosquitoes lured by odour cues from individuals sleeping nearby [24–26]. According to Garrett-Jones and Magayuka, the CDC LT-untreated bed net combination enhances the use of the trap for estimating Anopheles biting rates [26]. Compared to the HLC, CDC LTs are easy to use, have considerably lower costs to operate, are easily scalable and reduce human reliance. Mechanical malfunctioning and battery problems, highlighted as the main limitations.
of these traps usually occur on a minimal scale and faulty traps are often conveniently excluded from mosquito surveys [24]. CDC LTs are also used for outdoor mosquito catches, but they tend to perform poorly compared to when used indoors [27]. Although generally regarded as a reliable mosquito trap [24, 28] there is no clear consensus on the CDC LT performance relative to the HLC and their comparative efficacy to estimate populations of malaria vectors appears to vary based on the local settings [17, 22, 29–33].

The host/human decoy trap (HDT) (Figure 1), was first trialled against Anopheles mosquitoes in an attempt to cover a malaria vector monitoring gap for outdoor biting populations in Burkina Faso [34]. The trap optimises mosquito attraction by use of a combination of odour and visual stimuli and a thermal signature in the range equivalent to the human body temperature. Host odour emanating from a protected human in a nearby tent is blown down a plastic pipe and delivered around a visually conspicuous adhesive trap kept warm at 35±5°C by a heating mechanism, usually hot water (Figure 1D). The HDT is a promising entomological surveillance tool based on several studies that demonstrate its capacity to catch a wide range of exophilic mosquito species [34–38].

The goal of this study was to compare the CDC LT and HDT against the HLC for measuring biting behaviours of different Anopheles mosquitoes in rural Tanzania and to determine if the methods can replace the HLC for use in routine entomological surveillance.

**Methods**

**Study area**

The study area was in Ulanga District, south-eastern Tanzania (Figure 2). Ulanga is located in the wider Kilombero River valley. The region is characterised by a hot-humid climate, seasonal floodplains and irrigated rice paddies. The main malaria vectors are An. funestus and An. arabiensis [1, 39–41].

**Study design**

Two community randomized studies to evaluate the effectiveness of two new indoor residual spraying (IRS) products were conducted in 2017 (Study 1) and in 2019 (Study 2). Detailed descriptions of the IRS trials are presented in two papers (in preparation). The mosquito surveys were performed by HLC, the CDC LT and the HDT in separate houses. Sampling was partially randomised with population clusters (villages) selected close to rice paddies where high mosquito densities were presumed to occur and study houses were randomly selected within the villages. Overall, 19 villages were surveyed; Study 1 covered ten villages while Study 2 covered 14 villages that partly overlapped five villages from Study 1. The villages were paired into intervention and control arms and were separated by at least 2km to limit mosquito migration between treatment arms. House surveys were conducted to collect data on household characteristics such as the number of occupants, number of sleeping spaces, presence of pets and livestock, materials used on house walls, roof, ceiling, floor, and condition of eaves, window and door screening. The global positioning system (GPS) coordinates for house locations were recorded for all surveyed households.

**Human landing catch (HLC) collections**

The HLC surveys followed the WHO guidelines [42]. Two catchers collected mosquitoes indoors and outdoors, alternating positions every hour. Collections were performed for 45 minutes followed by 15 minutes break. The catchers received doxycycline for malaria prophylaxis and were tested weekly for malaria infection using Bioline Malaria Ag Pf/Pan rapid diagnostic tests. Mosquitoes were collected from 18:00PM to 06:00AM in three randomly selected houses per village. The surveys were repeated for six nights per month for five months in Study 1 and for eight months in Study 2.

**CDC LT collections**

The standard miniature CDC LT (Model 512; John W. Hock Company, Gainesville, FL.) was used for the surveys (Figure 1B). Traps were set indoors at sleeping spaces protected by ITNs, at the foot end of the bed, with the light source positioned at approximately 0.7m from the ground as described by Mboera et al [43]. The traps were operated from 18:00 PM to 06:00 AM in three randomly selected houses per village in Study 1 and in four randomly selected houses per village in Study 2. The traps were used for six nights per month for five months in Study 1 and for 20 nights per month for 8 months in Study 2.

**Human decoy trap (HDT) collections**

The HDT used in this study was a modification of the standard Biogents, Regensburg, Germany, developed as described by Hawkes and colleagues [44] and is shown in Figure 1D. HDT surveys were conducted as described by Hawkes and colleagues [34] and in accordance with the WHO general guidelines [42]. The traps were operated outdoors between 18:00PM to 06:00AM in 4 randomly selected houses per village and were repeated monthly for up to 3 months. The HDT surveys were only done in Study 2.

**Sorting and molecular identification of mosquitoes**

Field technicians sorted female adult mosquitoes morphologically to separate Anopheles mosquitoes. A sample of sibling Anopheles gambiae s.l. and An. funestus s.l. species were further sorted in the lab by polymerase chain reaction (PCR).

**Sporozoite detection in mosquito salivary glands**

Enzyme linked immunosorbent assays (ELISA) was used for detection of Plasmodium falciparum circumsporozoite protein (CSP) in the salivary glands of mosquitoes [45]. Detection of P. falciparum parasites was performed from heads and thoraxes for pooled mosquito samples, separately for An. arabiensis and An. funestus. Sample pooling was done by house ID, date and hour of collection and by trap type. The optical density of post-ELISA lysate were measured at 405 – 414nm after 45 minutes using ELISA plate reader machine [45].

**Data analysis**
Violin plots were used to display the distribution of the number of mosquitoes caught per trap per night. Due to skewness, the counts were log transformed by first adding a value of 1 to the number of mosquitoes (n) per trap per night i.e. log (n+1). Nightly trap catches were summarised using Williams’ means and medians with 90% central ranges. The relative proportions of *An. funestus and An. arabiensis* mosquito species caught by the traps were estimated using a logistic regression model with a random effect for house and date. The association between trap type and the number of mosquitoes caught was estimated by negative binomial regression with random effects for house and date and fixed effects for household size, livestock and domestic animals, house screening, IRS treatment, ITNs use, seasonality, and whether the measurements were taken as part of Study 1 or 2 (Supplementary Tables 1, 2 and 3).

Agreement for individual catches could not be assessed since there were no paired observations for the same households and nights. Instead, collections were aggregated by village and month to calculate the geometric mean number of mosquitoes caught per house per night for each trap.

The Bland and Altman approach [46] was used to assess agreement between the trap types, providing estimates of the overall bias and the variability. The bias was measured by the ratio of the geometric mean for each trap type (HDT or CDC) compared to the geometric mean using HLC, calculated for the village-months. The ratios were logarithmically transformed (because the distribution of the ratios was skewed). The log ratios were then plotted against the HLC density [47, 48]. The HLC density rather than the mean of two trap types were used because HLC was considered to be a gold standard. The estimates of the variability were presented as 95% limits of agreement, which represent the range in which 95% of the ratios were expected to lie. The mean bias and limits of agreement were estimated by the regression approach as described by Bland and Altman [49].

To investigate the effect of the trap on the mean ratio by density, a regression model was fitted with the log ratio as the outcome variable and HLC density as the explanatory variable. This way, an estimate of the effect of mosquito densities on the ratio of the geometric means of CDC LT (or HDT) to HLC could be obtained. The effect of mosquito densities on the variability and limits of agreement was estimated by regressing the absolute values of the residuals of the previous model on HLC catches. Village-months with 10 or less CDC LT and indoor HLC collection pairs were excluded from the agreement analysis due to stochasticity.

The prevalence of *P. falciparum* CSP ELISA positive mosquitoes was estimated for each trap type. Due to a very low sporozoite prevalence, no comparative analyses were made between the traps.

The statistical analyses were performed in Stata (16.1, StataCorp LLC, College Station, TX) and in R version 4.0.3 (R Foundation for Statistical Computing, Vienna, Austria).

**Results**

Altogether, there were 6,013 CDC LT, 339 indoor HLC, 136 HDT and 195 outdoor HLC collections. A greater number of *An. funestus* (66,807) than *An. arabiensis* (14,606) adult females were caught. The traps also caught a total 75,248 *Culex* spp mosquitoes, known vectors of other disease-causing pathogens and a common source of biting nuisance throughout the tropics. The number of mosquitoes collected per trap per night were generally low across all traps throughout the study, with a skewed distribution (Figure 3) and (Table 1). The skew was largely due to collections when no mosquitoes were caught by either of the traps but were included in the analysis since such observations are frequently encountered in natural populations. There was substantial variation in the number of mosquitoes caught per trap per night (Table 1).

The proportions of *An. arabiensis* relative to *An. funestus* in the CDC LTs and HDTs were lower than that captured by indoor and outdoor HLC, respectively (Figure 4).

Overall, the CDC LTs caught approximately a third as many *An. arabiensis* (Adjusted rate ratio (Adj.RR) = 0.35 (95% confidence interval (CI) = 0.27-0.46)) and about two-thirds as many *An. funestus* (Adj.RR = 0.63 (95% CI = 0.51-0.79)) compared to indoor HLC (Table 2). The HDT caught much lower numbers of *An. arabiensis* (Adj.RR = 0.04 (95% CI: 0.01-0.14)) and *An. funestus* (Adj.RR = 0.10 (95% CI: 0.07-0.15)) compared to the outdoor HLC. The estimated rate ratios for CDC LT and HDT for *Culex* spp were 0.82 (95% CI: 0.67-1.01) and 0.20 (95% CI: 0.14-0.29), respectively.

Aggregating the trap collections per village and per month gave a total of 116 CDC LT and indoor HLC pairs with a median of 66 (90% central range (CR): 6-89) collections per village-month and 40 HDT and outdoor HLC pairs with a median of 6 (90% CR: 4-9).

Geometric mean mosquito catches per village-month by the CDC LT and indoor HLC and by the HDT and outdoor HLC appeared to be positively associated (Figure 5). The mean ratios of geometric means of HDT or CDC LT to HLC and limits of agreement were dependent on mosquito density for all species (Figure 6). The mean ratios decreased significantly with higher HLC catches, indicating that trap efficiency was lower at higher mosquito densities. The limits of agreement for the village-months were wide across most of the range of HLC densities in this study but decreased for higher densities.

*Plasmodium falciparum* infection rates for *An. arabiensis* and *An. funestus* caught by the different traps were low (Table 3). Only CDC LTs caught any infected *An. arabiensis* mosquitoes and estimated a higher prevalence of infected *An. funestus* compared to indoor HLC. HDT did not catch any infected mosquitoes.

**Discussion**

Monitoring malaria vectors requires accurate, safe and reliable mosquito traps that can be deployed at scale. Despite being the most accurate measure of human exposure, the use of the HLC for the continuous exercise of monitoring malaria vectors is discouraged due to safety concerns. The primary goal of this study was to measure the efficacy relative to HLC of the CDC LT and the HDT to estimate the numbers of different species of host-seeking female *Anopheles* mosquitoes in Ulanga, Tanzania and to determine the suitability of the methods to replace the HLC for routine malaria entomological monitoring in the region.
Controlling for other effects influencing mosquito densities, the CDC LT caught roughly a third as many \textit{An. arabiensis} and about two thirds as many \textit{An. funestus} as the HLC overall, while the HDT barely caught a tenth of these species compared to the HLC. Although these mean estimates highlight the relative capacities of the traps in general, they have limited relevance in comparing the methods under diverse field settings where mosquito densities are likely to change even across fine spatial and temporal scales [22]. Instead, agreement analysis has been proposed by statisticians, whereby traps are compared on the basis of the overall bias and the variability of a series of matched mosquito collections spanning different location and time points [49, 50]. In the present study, compared to the HLC in matched village-month collections, the CDC LT and the HDT underestimated \textit{An. arabiensis} and \textit{An. funestus} biting and their performance was poorer at high mosquito densities. Mathenge and colleagues [31] explained that this trend may be due to reduced attentiveness of catchers performing the tedious HLC exercise at low mosquito densities. The limits of agreement representing the ratios of geometric mean catches per village-month to the HLC were quite wide, although this declined with increasing abundance of mosquitoes. High variability in the observed ratios presented a challenge to translate \textit{Anopheles} biting rates via consistent algorithms between the CDC LT and indoor HLC and between the HDT and outdoor HLC thereby rendering the use of the methods as HLC proxies for estimating \textit{Anopheles} biting at the village-month level difficult. However, the variability would be expected to reduce if the comparative estimates are aggregated at periods longer than a month and for areas larger than the villages of this study. In a trial for instance, where absolute numbers of mosquitoes are required to evaluate the effects of treatment arms, the regression equations used in the agreement analysis (Figure 6) could be employed as the conversion algorithms to account for the density-dependent bias of the traps.

Although the sporozoite rates data collected was not sufficient to conduct meaningful statistical comparisons between the CDC LT and the indoor HLC, the proportion of mosquitoes that were infected was higher in the CDC LT than in the indoor HLC samples, a finding similar to that of Mbogo and colleagues in Kilifi [33]. If indeed the CDC LT has higher sensitivity for measuring infection rates of mosquitoes, stemming from the biological premise that older mosquitoes are more likely to be infected, and that the CDC LT has a tendency to catch older mosquitoes [51], then the method is preferable for evaluating the impact of vector control programs.

Past studies of the CDC LT and the HDT (Table 1), suggest that the performance of these traps may also differ depending on several factors. For instance, in terms of numbers caught, the CDC LT under- [52] or out-performed [17, 30] HLC, independent of the mosquito species, but in some circumstances its performance differed based on the caught populations [22, 31]. Other observed sources of variation included location [35], dissimilarities indoors and outdoors [29, 51] and the presence or absence of ITNs [28]. Overgaard and colleagues observed that the results of CDC LT efficacy also varied by the different statistical analyses of their study [29], highlighting need to be aware and reconcile possible methodological inconsistencies as well. The choice of host decoy i.e whether cow or human [38], location [35, 37] and seasonality [34] were among the factors observed to influence the HDT performance.

Taken together, if used cautiously with case-by-case appreciation of its limitations, the CDC LT is a suitable and necessary entomological surveillance tool for indoor foraging mosquitoes particularly in light of the safety concerns with HLC. In any case, the traps are more objective since they are less prone to human sources of error; they are more acceptable within households than catchers visiting at night, and are convenient to deploy on largescale [24, 34, 38]. However, for measuring the EIR, concurrent use of the HLC on a limited scale is still crucial to calibrate the CDC LT estimates.

The HDT’s poor performance in largescale surveys has been ascribed mostly to operational challenges due to its design [35]. The field personnel involved in the surveys of this study mentioned logistical difficulties of transporting and setting up the traps from location to location and in obtaining and heating large volumes of water in remote settings. The CDC LTs adapted for outdoor surveys [35, 53] and the furvela tent trap (FTT) [35] are some of the possible alternatives for outdoor biting surveys and where necessary, limited use of the HLC.

Conclusion

Although the CDC LT caught fewer mosquitoes than the indoor HLC in this study, the traps have shown similar or better efficiency to the HLC elsewhere. The tendency of the traps to under- or oversample host-seeking anophelines can be resolved by regression methods with reference to the HLC, as long as the limits of agreement are reasonably narrow. They proved extremely efficient for estimating indoor mosquito density and sporozoite rate. Therefore, in light of the ethical problems presented by HLC use, the CDC LT could be considered for routine surveys or for estimating the efficacy of vector control tools deployed at scale with the HLC only used to estimate human exposure parameters needed to estimate EIR. The present design of the HDT is not amenable for use to conduct largescale entomological surveys.

Declarations

Ethical clearance and consent to participate

The studies received ethical clearance from the Medical Research Coordinating Committee of the Tanzanian National Institute of Medical Research. The reference numbers were as follows: Study 1: NIMR/HQ/R.8a/Vol.IX/1725 & 2270 and Study 2: NIMR/HQ/R.8a/Vol. IX/2894). Clearance by the Ifakara Health Institute Review Board (IHI-IRB) was issued under the following reference numbers: Study 1: IHI IRB 021/2016 & 015/2017 and Study 2: IHI/IRB/No: 031-2018). A written informed consent was obtained beforehand from heads of all households that participated in these studies.

Consent for publication

We would like to thank the National Institute for Medical Research (NIMR) for permission to conduct research and to publish this paper through letter reference number NIMR/HQ/P12 VOL XXXIII/79.
Availability of data and materials

The datasets used and or analysed in this study are available from the corresponding author upon reasonable request

Author information

Affiliations

Swiss Tropical and Public Health Institute, Basel, Switzerland
Isaac Haggai Namango, Amanda Ross, Sarah Moore, Manuel Hetzel.

University of Basel, Basel, Switzerland
Isaac Haggai Namango, Amanda Ross, Sarah Moore, Manuel Hetzel.

Ifakara Health Institute, Bagamoyo, Tanzania
Isaac Haggai Namango, Carly Marshall, Adam Saddler, David Kaftan, Frank Tenywa, Noely Makungwa, Olukayode Odufuwa, Godfrey Ligema † Hassan Ngonyani, Isaya Matanila, Jason Moore, Sarah Moore.

British Columbia Centre for Excellence in HIV/AIDS, British Columbia, Vancouver, Canada
Carly Marshall.

Telethon Kids Institute, Perth, Australia
Adam Saddler.

Marquette University, Milwaukee, Wisconsin, United States of America
David Kaftan.

London School of Hygiene and Tropical Medicine, London, United Kingdom
Olukayode Odufuwa

Innovative Vector Control Consortium, Dar es Salaam, Tanzania
Jameel Bharmal.

Correspondence to Isaac Haggai Namango: isaac.namango@swisstph.ch

Authors’ contributions

Conceived and designed the study: CM and SM. Implemented the study: CM, AS, DK, FT, NM, OO, GL (Deceased), HN, IM, JB, JM and SM. Conducted or contributed to the analysis: IHN, SM, AR and MH. Drafted or edited the manuscript: IHN, CM, AS, AR, DK, FT, OO, JB, SM, MH. All authors read and approved the final manuscript.

Acknowledgements

We thank the community volunteers for participating in the surveys and the residents of Ulanga for accommodating the survey activities in and about their households. This paper is dedicated to the memory of our colleague Godfrey Ligema.

Competing interests

The authors declare that they have no competing interests.

Funding

Funding for this study was provided by the Ifakara Health Institute (IHI)-Vector Control Product Testing Unit (VCPTU).

References
1. Finda MF, et al., *Linking human behaviours and malaria vector biting risk in south-eastern Tanzania*. Plos One, 2019. 14(6).

2. Monroe A, et al. Human behaviour and residual malaria transmission in Zanzibar: findings from in-depth interviews and direct observation of community events. Malar J. 2019;18(1):220–0.

3. Monroe A, et al., *Measuring and characterizing night time human behaviour as it relates to residual malaria transmission in sub-Saharan Africa: a review of the published literature*. Malaria Journal, 2019. 18.

4. Monroe A, et al., *Outdoor sleeping and other night-time activities in northern Ghana: implications for residual transmission and malaria prevention*. Malaria Journal, 2015. 14.

5. Msellmu D, et al. The epidemiology of residual Plasmodium falciparum malaria transmission and infection burden in an African city with high coverage of multiple vector control measures. Malar J. 2016;15(1):288.

6. World Health Organisation. *Manual on practical entomology in malaria. Part II. Methods and techniques*. 1975, WHO Division of Malaria and Other Parasitic Diseases.: Geneva. p. 195p.

7. Monroe A, et al. Methods and indicators for measuring patterns of human exposure to malaria vectors. Malar J. 2020;19(1):1–14.

8. Lima JB, et al. Is there an efficient trap or collection method for sampling Anopheles darlingi and other malaria vectors that can describe the essential parameters affecting transmission dynamics as effectively as human landing catches? - A Review. Mem Inst Oswaldo Cruz. 2014;109(5):685–705.

9. Service M. Critical-review of procedures for sampling populations of adult mosquitoes. Bull Entomol Res. 1977;67(3):343–82.

10. Mboera L. Sampling techniques for adult Afrotropical malaria vectors and their reliability in the estimation of entomological inoculation rate. Tanzania Journal of Health Research. 2005;7(3):117–24.

11. Service M. Mosquito ecology. *Field sampling methods*. 2nd ed. London: Elsevier; 1993.

12. Gimming JE, et al. Incidence of malaria among mosquito collectors conducting human landing catches in western Kenya. 2013;88(2):301–8.

13. Wototdo AN, et al. No difference in the incidence of malaria in human-landing mosquito catch collectors and non-collectors in a Senegalese village with endemic malaria. PloS one. 2015;10(5):e0126187.

14. Ndebele P, Musesengwa R. View point: Ethical dilemmas in malaria vector research in Africa: making the difficult choice between mosquito, science and humans. Malawi medical journal: the journal of Medical Association of Malawi. 2012;24(3):65–8.

15. Chandler J, Highton R, Hill M. Mosquitoes of the Kano Plain, Kenya. I. Results of indoor collections in irrigated and nonirrigated areas using human bait and light traps. J Med Entomol. 1975;12(5):504–10.

16. Kenea O, et al., *Comparison of two adult mosquito sampling methods with human landing catches in south-central Ethiopia*. Malaria Journal, 2017. 16.

17. Briét OJ, et al. Applications and limitations of Centers for Disease Control and Prevention miniature light traps for measuring biting densities of African malaria vector populations: a pooled-analysis of 13 comparisons with human landing catches. Malar J. 2015;14(1):1–13.

18. Kilama WL. Health research ethics in malaria vector trials in Africa. Malaria Journal. 2010;9(3):1–9.

19. World Health Organization. Global technical strategy for malaria 2016-2030. World Health Organization; 2015.

20. World Health Organization. *Malaria entomology and vector control*. 2013.

21. Takken W, Knols BG. Odor-mediated behavior of Afrotropical malaria mosquitoes. Ann Rev Entomol. 1999;44(1):131–57.

22. Wong J, et al., *Standardizing operational vector sampling techniques for measuring malaria transmission intensity: evaluation of six mosquito collection methods in western Kenya*. Malaria Journal, 2013. 12.

23. Odotoyinbo J. Preliminary investigation on the use of a light-trap for sampling malaria vectors in the Gambia. Bull World Health Organ. 1969;40(4):547.

24. Lines J, et al. Monitoring human-biting mosquitoes (Diptera: Culicidae) in Tanzania with light-traps hung beside mosquito nets. Bull Entomol Res. 1991;81(1):77–84.

25. Costantini C, et al. Relationship to human biting collections and influence of light and bednet in CDC light-trap catches of West African malaria vectors. Bull Entomol Res. 1998;88(5):503–11.

26. Garrett-Jones C, Magayuka SA, World Q, Health, *Studies on the natural incidence of Plasmodium and Wuchereria infections in anopheles in rural East Africa / by C. Garrett-Jones, S. A. Magayuka*. 1975, World Health Organization: Geneva.

27. Faye O, et al., *Comparative efficacy of the use of CDC light traps and humans to sampling anopheles populations. Results obtained in the area of Bignona (Senegal)]*. Bulletin de la Societe de pathologie exotique (1990), 1992. 85(2): p. 185-189.

28. Magbity E, et al. How reliable are light traps in estimating biting rates of adult Anopheles gambiae s.l (Diptera: Culicidae) in the presence of treated bed nets? Bull Entomol Res. 2002;92(1):71–6.

29. Overgaard HJ, et al. Light traps fail to estimate reliable malaria mosquito biting rates on Bioko Island, Equatorial Guinea. Malaria Journal. 2012;11(1):56.

30. Mathenge EM, et al., *Comparative field evaluation of the Mbta trap, the Centers for Disease Control light trap, and the human landing catch for sampling of malaria vectors in western Kenya*. 2004.

31. Mathenge EM, et al. Comparative performance of the Mbta trap, CDC light trap and the human landing catch in the sampling of Anopheles arabiensis, An. funestus and culicine species in a rice irrigation in western Kenya. Malar J. 2005;4(1):1–6.

32. Fornadel CM, Norris LC, Norris DE. Centers for Disease Control light traps for monitoring Anopheles arabiensis human biting rates in an area with low vector density and high insecticide-treated bed net use. Am J Trop Med Hyg. 2010;83(4):838–42.

33. Mbogo CN, et al. Evaluation of light traps for sampling anopheline mosquitoes in Kilifi, Kenya. J Am Mosq Control Assoc. 1993;9(3):260–3.

34. Hawkes FM, et al. Exploiting Anopheles responses to thermal, odour and visual stimuli to improve surveillance and control of malaria. Sci Rep. 2017;7(1):17283.
35. Abong'o B, et al., Comparison of four outdoor mosquito trapping methods as potential replacements for human landing catches in western Kenya. Parasites & vectors, 2021. 14(1): pp. 1–15.
36. Davidson JR, et al., Characterization of vector communities and biting behavior in South Sulawesi with host decoy traps and human landing catches. Parasites & Vectors, 2020. 13(1): pp. 1–17.
37. Zembere K, et al. The human-baited host decoy trap (HDT) is an efficient sampling device for exophagic malaria mosquitoes within irrigated lands in southern Malawi. bioRxiv; 2021.
38. Abong'o B, et al. Host Decoy Trap (HDT) with cattle odour is highly effective for collection of exophagic malaria vectors. 11: Parasites & Vectors; 2018.
39. Lwetoijera DW, et al. Increasing role of Anopheles funestus and Anopheles arabiensis in malaria transmission in the Kilombero Valley, Tanzania. Malar J. 2014;13:331.
40. Kaindoa EW, et al. Interventions that effectively target Anopheles funestus mosquitoes could significantly improve control of persistent malaria transmission in south–eastern Tanzania. PloS one. 2017;12(5):e0177807.
41. Finda MF, et al., Dramatic decreases of malaria transmission intensities in Ifakara, south-eastern Tanzania since early 2000s. 2018. 17(1): p. 362.
42. World Health Organization, Division of Malaria, and. Parasitic O, Diseases. Manual on practical entomology in malaria. Part 2, Part 2. 1975, Geneva; [London]: World Health Organization; [H.M.S.O.].
43. Mboera LE, et al. Short report: Influence of centers for disease control light trap position, relative to a human-baited bed net, on catches of Anopheles gambiae and Culex quinquefasciatus in Tanzania. Am J Trop Med Hyg. 1998;59(4):595–6.
44. Hawkes F, et al., Constructing a Host Decoy Trap for malaria vector sampling. 2018.
45. Wirtz RA, et al. Development and evaluation of an enzyme-linked immunosorbent assay for Plasmodium vivax-VK247 sporozoites. J Med Entomol. 1992;29(5):854–7.
46. Altman D, Bland J. Measurement in Medicine: The Analysis of Method Comparison Studies. The Statistician. 1983;32:307–17.
47. Krouwer JS. Why Bland–Altman plots should use X, not (Y+ X)/2 when X is a reference method. Statistics in medicine. 2008;27(5):778–80.
48. Nevill AM, Atkinson G. Assessing agreement between measurements recorded on a ratio scale in sports medicine and sports science. Br J Sports Med. 1997;31(4):314.
49. Bland JM, Altman DG. Measuring agreement in method comparison studies. Stat Methods Med Res. 1999;8(2):135–60.
50. Bland JM, Altman D. Statistical methods for assessing agreement between two methods of clinical measurement. The lancet. 1986;327(8476):307–10.
51. Hii J, et al., Comparison between anopheline mosquitoes (Diptera: Culicidae) caught using different methods in a malaria endemic area of Papua New Guinea. Bulletin of entomological research, 2000. 90(3): pp. 211–9.
52. Oketch F, et al., Comparative evaluation of methods used for sampling malaria vectors in the Kilombero Valley, South Eastern Tanzania. The open tropical medicine journal., 2008. 1: p. 51–55.
53. Degefa T, et al. Indoor and outdoor malaria vector surveillance in western Kenya: implications for better understanding of residual transmission. Malaria Journal. 2017;16(1):443.

Tables
Table 1. Number of trap collections and number of mosquitoes caught per trap per night.

| Trap type | An. arabiensis |  | An. funestus |  | Culex spp |  |
|-----------|----------------|---|--------------|---|-----------|---|
|           | Total collections | Total caught | Williams’ mean (95%CI) | Median (90% central range) | Total caught | Williams’ mean (95%CI) | Median (90% central range) | Total caught | Williams’ mean (95%CI) | Median (90% central range) |
| Indoor HLC | 339 | 3380 | 2.39 | 1(0-61) | 0-180 | 3934 | 4.22 | 5(0-58) | 0-147 | 4803 | 6.51 | 7(0-46) |
|           |     |     | (1.93-2.91) |     |     |     | (3.53-5.02) |     |     | (5.58-7.57) |     |
| CDC LT | 6013 | 10281 | 0.51 | 0(0-7) | 0-658 | 59276 | 4.61 | 5(0-39) | 0-240 | 66459 | 5.01 | 5(0-45) |
|           |     |     | (0.48-0.54) |     |     |     | (4.45-4.78) |     |     | (4.84-5.19) |     |
| Outdoor HLC | 195 | 940 | 1.56 | 1(0-23) | 0-139 | 3408 | 4.14 | 9(1-63) | 0-143 | 3460 | 11.71 | 11(2-58) |
|           |     |     | (1.18-2.00) |     |     |     | (3.48-4.91) |     |     | (10.15-13.48) |     |
| HDT | 136 | 5 | 0.02 | 0(0-0) | 0-2 | 189 | 0.77 | 0(0-7) | 0-11 | 526 | 2.33 | 3(0-12) |
|           |     |     | (0.00-0.05) |     |     |     | (0.56-0.99) |     |     | (1.86-2.88) |     |

The Williams’ means were computed by exponentiating the arithmetic means of the log transformed nightly catches per trap. A value of 1 was added to the figures of caught mosquitoes prior to the logarithmic transformation i.e. log (n+1).
Table 2. The estimated effect of the CDC LT and the human decoy trap (HDT) compared to the human landing catch (HLC).

| Trap type   | An. arabiensis | An. funestus | Culex spp |
|-------------|----------------|--------------|-----------|
|             | Adj.RR† (95%CI) | Adj.RR† (95%CI) | Adj.RR† (95%CI) |
|             | p value         | p value      | p value   |
| Indoor HLC  | 1*              | 1*           | 1*        |
| CDC LT      | 0.35            | 0.63         | 0.82      |
|             | (0.27-0.46)     | (0.51-0.79)  | (0.67-1.01) |
|             | < 0.001         | < 0.001      | 0.061     |
| Outdoor HLC | 1*              | 1*           | 1*        |
| HDT         | 0.04            | 0.10         | 0.20      |
|             | (0.01-0.14)     | (0.07-0.15)  | (0.14-0.29) |
|             | < 0.001         | < 0.001      | < 0.001   |

†The adjusted mosquito sampling rate ratios (Adj. RR) and 95% confidence intervals (95%CI) were estimated from negative binomial regression models. The models included random effects for day and house, and fixed effects for the household size, livestock and pets reared, house screening, IRS treatment, ITNs use, seasonality, and whether the trap surveys were conducted in Study 1 or 2.

1* reference method.

Table 3. Plasmodium falciparum infection rates for An. arabiensis and An. funestus collected by different traps.

| Malaria vectors positive by ELISA test |
|---------------------------------------|
| An. arabiensis | An. funestus | Total |
| Trap type | positive | tested | % positive | positive | tested | % positive | positive | tested | % positive |
| Indoor HLC | 0 | 286 | 0 | 12 | 998 | 1.20 | 12 | 1,284 | 0.93 |
| CDC LT | 10 | 1,461 | 0.68 | 255 | 5,701 | 4.47 | 265 | 7,162 | 3.70 |
| Outdoor HLC | 0 | 335 | 0 | 10 | 966 | 1.04 | 10 | 1,301 | 0.77 |
| HDT | 0 | 3 | 0 | 0 | 39 | 0 | 0 | 42 | 0 |

% positive represents the number of mosquitoes with a positive P. falciparum circumsporozoite protein (CSP) ELISA test divided by the total number of mosquitoes tested.

ELISA = Enzyme-linked immunosorbent assay.
Table 4. Some past studies of the efficacy relative to HLC of the CDC LT and HDT against *Anopheles* species.

| No. | Area of study | Dominant anophelines | Relative efficacy: Ratio to HLC (95% confidence intervals) | Was trap efficacy dependent on mosquito density? | Reference |
|-----|---------------|----------------------|-----------------------------------------------------------|------------------------------------------------|-----------|
| 1.  | **CDC LT**    |                      |                                                          |                                                 |           |
| 1.  | **Mosquito species** |                      |                                                          |                                                 |           |
| 1.  | Ulanga, Tanzania | *An. arabiensis*     | 0.35 (0.27-0.46)                                          | Yes                                            | This study|
|     |                | *An. funestus*       | 0.63 (0.51-0.79)                                          | Yes                                            |           |
| 2.  | Ulanga, Tanzania | 98% *An. gambiae* s.l | 0.33 (0.24-0.46)                                          | NA                                             | Okumu *et al.* 2008 [52] |
|     |                | 2% *An. funestus*    | 0.82 (0.61-1.10)                                          | NA                                             |           |
| 3.  | Kenya, Zambia, Burkina Faso, Ghana, Tanzania | *An. gambiae* s.l | 1.06 (0.68-1.64)                                          | Yes                                            | Briët *et al.* 2015 [17]** |
|     |                | *An. funestus*       | 1.37 (0.70-2.68)                                          | Yes                                            |           |
| 4.  | Lwanda, Kenya  | 74% *An. gambiae* s.l | 1.86 (1.73-2.00)                                          | No                                             | Mathenge *et al.* 2004 [30]* |
|     |                | 26% *An. funestus*   | 1.91 (1.66-2.19)                                          | No                                             |           |
| 5.  | Ahero, Kenya   | *An. arabiensis*     | 0.56 (0.49-0.66)                                          | Yes                                            | Mathenge *et al.* 2005 [31] |
|     |                | *An. funestus*       | 1.19 (1.03-1.37)                                          | Yes                                            |           |
| 6.  | Rarieda, Kenya | *An. gambiae* s.l    | 1.18 (0.55-2.54)                                          | NA                                             | Wong *et al.* 2013 [22]  |
|     |                | *An. funestus*       | 0.69 (0.49-0.98)                                          | NA                                             |           |
| 1.  | **ITNs vs no ITNs** |                      |                                                          |                                                 |           |
| 7.  | Bo, Sierra Leone | *An. gambiae* s.l   | 0.88 (0.72-1.05)                                          | No (without ITNs) Yes (with ITNs)                | Magbity *et al.* 2002 [28]‡ |
| 1.  | **Indoors vs outdoors** |                      |                                                          |                                                 |           |
| 8.  | Wosera, Papua New Guinea | *An. koliensis* | 0.28 (0.27-0.29)                                          | Yes                                            | Hii *et al.* 2000 [51] |
|     |                | *An. panctulatus*    | 0.10 (0.09-0.11)                                          | Yes                                            |           |
|     |                | *An. karwari*        | 0.12 (0.11-0.13)                                          | Yes                                            |           |
|     |                | *An. farauti* s.l    | 0.07 (0.06-0.09)                                          | Yes                                            |           |
|     |                | *An. longirostris*   | 0.12 (0.08-0.15)                                          | Yes                                            |           |
|     |                | *An. bancroftii*     | 0.20 (0.15-0.27)                                          | Yes                                            |           |
| 9.  | Bioko Island, Equatorial Guinea | *An. gambiae* s.s & | 0.12 (0.11-0.14)                                          | Yes (indoors) No (outdoors)                      | Overgaard *et al.* 2012 [29]† |
|     |                | *An. melas*          | 0.36 (0.32-0.40)                                          | (Mongola area)                                 |           |
|     |                |                    | 0.10 (0.09-0.12)                                          | (Arena Blanca area)                            |           |
|     |                |                    | 0.07 (0.05-0.09)                                          | (Riaba area)                                   |           |
|     |                |                    | 0.13 (0.10-0.16)                                          | (Riaba area)                                   |           |
| 1.  | **Location**   |                      |                                                          |                                                 |           |
| 10. | Nyando & Muhoroni, Kenya | *An. arabiensis* | 1.98 (1.01-3.86)                                          | NA                                             | Abongo *et al.* 2021 [35] |
|     |                | *An. funestus*       | 0.88 (0.37-2.11)                                          | NA                                             |           |
|     |                | *An. coustani*       | 3.03 (1.65-5.56)                                          | NA                                             |           |

1. **ITNs vs no ITNs**: With ITNs, Without ITNs
2. **Indoors vs outdoors**: Indoors, Outdoors
3. **Location**: Kakola-Ombaka area, Masogo area
| Location | Type of host bait | Cow-baited | Human-baited | Rainy season | Early dry season | Late dry season |
|----------|------------------|------------|--------------|--------------|-----------------|----------------|
| Ulanga, Tanzania | An. arabiensis | 0.04 (0.01-0.14) | | | | |
| | An. funestus | 0.10 (0.07-0.15) | | | | |
| 1. Type of host bait | Cow-baited | Human-baited | Cow-baited | Human-baited | Cow-baited | Human-baited |
| Kisumu & Homa Bay, Kenya | An. gambiae s.s & An. arabiensis & An. funestus & An. coustani | 7.08 (Kisian) | 0.17 (Kisian) | 0.60 (Homa Bay) | NA | NA |
| | | 8.34 (Homa Bay) | | | | |
| | | | | | | |
| 2. Location | Kakola-Ombaka area | Masogo area | Lakkang area | Pucak area | | |
| Nyando & Muhoroni, Kenya | An. arabiensis | 5.69 (2.98-10.86) | 1.32 (0.49-3.59) | NA | NA | NA |
| | An. funestus | 1.38 (0.60-3.18) | 0.66 (0.21-2.09) | NA | NA | NA |
| | An. coustani | 0.18 (0.09-0.37) | 2.88 (1.15-7.22) | NA | NA | NA |
| | An. pharoensis | NA | NA | NA | NA | NA |
| Chikwawa, Malawi | An. gambiae s.s & An. Arabiensis & An. coustani & An. quadriannulatus & An. tenebrosus | 1.03 (0.80-1.30) | | 1.03 (0.83-1.37) | | |
| Vallée de Kou, Burkina Faso | An. gambiae | 9.6 (9.4-9.7) | 2.2 (2.0-2.4) | 1.7 (1.3-2.0) | NA | NA |
| | An. pharoensis | 10.5 (10.4-10.7) | 2.8 (2.5-3.0) | 1.7 (1.3-2.1) | NA | NA |
| | An. coustani | NA | 18.6 (18.2-19.1) | | | |

NA = not assessed because of data scarcity
† ratio estimated for pooled mosquito species
‡ three CDC LTs were compared to two HLC catchers
Figure 1

Illustrations of mosquito traps.

Panel A: The human landing catch (HLC) technique showing a catcher transferring a trapped mosquito into a collection container. Panel B: The standard CDC LT (Model 512; John W. Hock Company, Gainesville, FL). Panel C: A study field assistant setting up a CDC LT inside a house. Panel D: The human decoy trap (HDT). A study field assistant preparing the tent to be occupied by a human.

Figure 2

Map of the study area.

Panel A shows house locations where mosquito surveys were conducted. Overlapping dots represent closely located households. Panels B and C show the locations of Ulanga District in Tanzania and of the study area in Ulanga District, respectively.

Figure 3

Density distribution of log nightly mosquito catches per trap.

The violin plots were plotted from log transformed mosquito numbers due to skewness. Because of zeros in the data, a value of 1 was added to the nightly numbers of mosquitoes prior to the logarithmic transformation.
Figure 4

The proportions of *Anopheles* mosquitoes caught by traps.

The relative proportions of (A) *An. arabiensis* versus *An. funestus* and (B) Anophelines versus culicines were estimated from logistic regression models adjusted for random effects of house and date. (The error bars represent 95% confidence intervals (CI)).

Figure 5

Mosquito catches per village-month by the CDC LT and indoor HLC (upper panels) and by HDT and outdoor HLC (lower panels).

Figure 6

Bland-Altman-based plots showing agreement between CDC LT and indoor HLC (upper panels) and between HDT and outdoor HLC (lower panels).

The solid lines (—) represent the mean ratios of geometric mean catches for the village-month for CDC LT or HDT compared to HLC (the overall bias). The regression equations used to estimate the overall biases are the translation algorithms that account for the density-dependence of the CDC LT or HDT effects relative to the HLC.

The dotted lines (-----) represent the 95% limits of agreement, in which 95% of the ratios were expected to lie.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- Additionalfiles.docx