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Estimating Dispersal, Survival time and Population size of Wild Aedes aegypti in Dar es Salaam, Tanzania using Self-Mark-Release-Recapture Method

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Abstract

Aedes-borne arboviral diseases represent a major global public health challenge, with vector control remaining the primary preventive strategy because there are no available antivirals or universal vaccines for most of these infections. This study quantified dispersal, survival time and population size of *Aedes aegypti* using a mosquito mark-release-recapture (MMRR) approach to generate ecological parameters required in implementing a release-based approaches for *Ae. aegypti* control. Wild *Ae. aegypti* pupae were placed beneath a marking unit covered with fluorescent dust-coated cloth-grids. Marked mosquitoes were recaptured within a 250m radius using BG-sentinel traps, prokopack aspirators, resting buckets and gravid traps. The overall mean distance travelled (MDT) was 94.5m(95%CI:83.4-105.7) and the maximum distance travelled was 156m. The average life expectancy (ALE) was 13.5 days(95%CI:12.2–14.8), with an average probability of daily survival (PDS) of 0.93(95%CI:0.92–0.94). Survival analysis showed that approximately 80% of male and female *Ae. aegypti* survived up to 10days. The estimated population size was 26,325 individuals within 200m radius of the marking device. These findings demonstrate that, *Ae. aegypti* exhibit limited dispersal and survive beyond dengue virus' average extrinsic incubation period (EIP) of 7-12days, providing ecological conditions conducive to sustain arboviral transmission. The results also provide critical parameters for optimizing release-based control strategies.

Introduction

Vector borne diseases cause approximately 700,000 deaths worldwide each year, accounting for about 17% of all deaths from infectious diseases [1]. After malaria vectors, *Aedes aegypti* and *Aedes albopictus* mosquitoes are the most important vectors of human diseases [1]. These mosquito species are invasive arboviral vectors distributed globally that transmit several arboviruses, including dengue, chikungunya and zika viruses [2–4]. Over recent decades, dengue, chikungunya and zika have emerged as major global health threats, expanding into many countries, including some with no previous transmission [5]. In the absence of antiviral therapies and universally effective vaccine for most *Aedes*-borne arboviral diseases, vector control remains the cornerstone of prevention and control. Since the 1950s, considerable success in mosquito vector control has been achieved through the use of insecticides such as pyrethroids, organophosphates, carbamates and organochlorines [6, 7]. However, the extensive use of these chemical interventions has selected for insecticide resistance among targeted mosquito populations, undermining the effectiveness of vector control programs.

The innovation of population level interventions such as the sterile insect technique (SIT) [8], the use of *Wolbachia*-based approaches and genetically modified mosquitoes [9] have been developed as alternative methods for controlling *Ae. aegypti*. The sterile insect technique involves sterilizing male mosquitoes, typically using ionizing radiation or genetic modification, before releasing them into the wild. When steriles mate with wild females, no viable offspring are produced [10, 11]. *Wolbachia*-based strategies use the naturally occurring endosymbiotic alpha-proteobacteria to either suppress mosquito populations or to reduce their capacity to transmit arboviruses. In population-suppression approaches, Wolbachia-infected males are released to mate with uninfected wild females, causing cytoplasmic incompatibility and the production of non-viable offspring [12]. In population-replacement approaches *Wolbachia* can reduce mosquito lifespan [13] thereby lowering vectorial capacity and protecting against viral infection [14, 15]. Similarly, genetically modified mosquito approaches involve releasing male mosquitoes that mate with wild females, and pass on genetic traits that result in offspring that either die before reaching adulthood or that become sterile [16]. Although they differ in mechanism, all these strategies have a common mode of application: male mosquitoes are mass reared, manipulated in the laboratory and then released into the field to mate with wild females, thereby reducing the reproductive potential or vectorial capacity of the wild population.

All of these interventions depend upon sufficient modified males mating with wild females. This underscores the need to understand key mosquito biological parameters such as dispersal patterns, flight range, survival and population size. Understanding these parameters is essential for designing release strategies as it provides guidance on the optimal

spatial and temporal intervals at which modified mosquitoes should be released, based on flight range and survival time, respectively. Furthermore, estimating the population size of the wild mosquito population is crucial, as it informs the approximate number of manipulated mosquitoes required to ensure sufficient mating with wild counterparts. Despite the obvious importance of these parameters, measuring them remains challenging. Most available age-grading approaches are destructive, including chemometric, genetic and spectroscopic methods [17]. Therefore, the mosquito mark-release-recapture (MMRR) technique is the only available method capable of measuring all these parameters without killing the mosquitoes [18, 19]. This method involves marking wild-caught or laboratory reared mosquitoes, using a variety of agents including paints, dyes, trace elements, fluorescent dusts and radioactive or stable isotopes [20], releasing and then recapturing them at defined time intervals at specific distances from the release point using entomological traps [19, 21]. In MMRR fluorescent dust is the most widely used marker due to its simplicity: it is applied externally on the mosquito's body and detection is performed using a UV-light torch or a fluorescent microscope [22].

Several studies have assessed *Aedes* mosquito movement and dispersal pattern through MMRR worldwide [23–29], with few studies in Africa (Table 1). In East Africa, particularly in Tanzania, existing MMRR studies have been limited to *Anopheles* mosquitoes [30–32]. To our knowledge, no recent study has investigated the dispersal patten, flight range, survival time and population size of wild *Ae. aegypti* mosquitoes, with the last study in Tanzania conducted over 50 years ago [33]. This knowledge gap poses significant setbacks for programs intending to implement any release-based interventions in the country, as these strategies require accurate information on such parameters. Therefore, the present study employed a self-marking release-recapture method to investigate the dispersal pattens, flight range and survival time of wild *Ae. aegypti* mosquitoes in Dar es Salaam. It also presents estimates of *Ae. aegypti* population size in the city, with the aim of informing vector control programs when planning and implementing dengue vector control.

Table 1
List of mosquito mark-release-recapture (MMRR) studies for *Aedes* mosquitoes conducted in Africa

Country	Parameters	Mosquito species	Recapture	Reference
Tanzania	Survival and population size	*Aedes aegypti*	Repeated	[33]
Kenya	Dispersal, population size and longevity	*Aedes aegypti*	Repeated	[34–36]
Reunion Island	Population size	*Aedes albopictus*	Single	[25, 37, 38]
Senegal	Dispersal, population size and survival	*Aedes vexans*	Single	[39]
Uganda	Dispersal, population size and longevity	*Aedes simpsoni*	Single	[40, 41]
Mauritius	Dispersal, survival and population size	*Aedes albopictus*	Single	[42, 43]

Results

Mosquito release and recapture

A total of 1,053 *Ae. aegypti* mosquitoes emerged from 1,956 pupae placed in the mosquito marking unit. Given a marking success rate of 0.86, as reported previously [32], it is assumed that 906 mosquitoes were considered successfully marked upon emerging from the marking unit. Of these, 66 mosquitoes were recaptured, corresponding to an overall recapture rate of 7.3%, with 6.2% (n = 28) females and 8.4% (n = 38) males (Table 2).

Table 2
Recaptured marked mosquitoes 21 days post emergence under a mosquito marking unit with different marking colours.

Colour	Number of placed and emerged pupae, and marked mosquitoes					Proportions of marked recaptured mosquitoes					
	Pupae	Emerged	Marked**	Marked Female*	Marked Male*	Total	Female	%	Male	%	Overall %
Red (Day 1)	495	120	104	52	52	23	15	28.8	8	15.4	22.1
Green (Day 2)	178	125	108	54	54	7	3	5.6	4	7.4	6.5
Yellow (Day 3)	546	113	98	49	49	9	0	0	9	18.4	9.2
Pink (Day 4)	737	695	598	299	299	27	10	3.3	17	5.7	4.5
Total	1956	1053	906	453	453	66	28	6.2	38	8.4	7.3

**Marked mosquitoes obtained by multiplying the emerged mosquitoes to the marking success correction factor (0.86) [32]

*Marked mosquito assuming that pupae emerged at 50:50 female: male ratio

DispersalThe overall mean distance travelled (MDT) by *Ae. aegypti* was 94.5m (95% CI: 83.4-105.7). There was no notable difference in MDT between female and male mosquitoes (Table 3). No clear pattern or decay in the number of mosquitoes was observed from the marking unit to the farthest recapture points, for either sex or for both sexes combined, with most mosquitoes being recaptured between 50m and 100m in all cases (Fig. 1). The maximum distance travelled (MaxDT) by *Ae. aegypti* was 156 m (Table 3), while the estimated flight range (FR) at which 50% and 90% of mosquitoes would fly were 58.4m (95% CI: 52.4m-66.4m) and 107m (95% CI: 95.1m-127m), respectively (Fig. 2).

Table 3
Mean and maximum distance travelled, population estimate and mean mosquito age of wild *Ae. aegypti* in Kinondoni district, Dar es Salaam.

Mosquito	MDT (m)	MaxDT (m)	PE	MMA (days)
Overall	94.5(83.4-105.7)	156	26,325	8.7
Female	95.2(76.0-114.3)	156	12,592	7.8
Male	94.0(80.6-107.5)	156	13,605	9.6

MDT=Mean Distance Travelled, MaxDT=Maximum Distance Travelled, PE=Population Estimate and MMA=Mean mosquito age

Survival Rate and Average Life Expectancy

The average age of recaptured *Ae. aegypti* was 8.7 days, with males living slightly longer (9.6 days) than females (7.8 days) (Table 3). The overall expected average life expectancy (ALE) of *Ae. aegypti* was 13.5 days (95% CI: 12.2–14.8) (Fig. 3), with probability of daily survival (PDS) of 0.93 (0.92–0.94). The ALE is derived from the constant rate of

recapturing mosquitoes until day 13 (Fig. 4), and indicated that both mosquito sexes can be expected to survive up to 13 days, beyond the extrinsic incubation period of 7–12 days for dengue viruses [44].

Population size

Using the Lincoln Index for population size estimation [45], the overall *Ae. aegypti* population density within 200m radius was estimated to be 26,325 individuals (Table 2). Male mosquitoes were slightly more abundant, with a density of 13,605 compared to 12,592 females (Table 2).

Age Effect on Aedes aegypti Flight

The recaptured marked mosquitoes were divided into two age groups: (1) ≤ 7 days old, representing mosquitoes that are usually less likely to be infectious for dengue, and (2) > 7 days old, representing mosquitoes that are more likely to be infectious, as they are within the extrinsic incubation period (EIP) of dengue viruses. Since the majority of mosquitoes were recaptured within the first and second annuli, flight distances were categorized into two groups: (1) ≤ 60 m, corresponding to only the first annulus, and (2) > 60 m, covering annuli 2–4. The results showed that younger *Ae. aegypti* were primarily recaptured at shorter distances, whereas

nearly half of the older mosquitoes dispersed beyond 60 m (Table 4). However, this difference was not statistically significant (IRR = 1.46, 95% CI: 0.84–2.53, p = 0.178) when comparing older mosquitoes to younger ones (IRR = 1) (Table 4) mainly due to small sample size.

Table 4
Incidence rate ratio of wild *Ae. aegypti* that flew different distances from a marking unit.

Age (Days)	≤ 60m			> 60m			overall		
	n (%)	IRR (95%CI)	p-value	n (%)	IRR (95%CI)	p-value	n (%)	IRR (95%CI)	p-value
≤ 7	13 (59.1)	1	-	11 (25.0)	1	-	24 (36.4)	1	-
> 7	9 (40.9)	0.81 (0.34–1.89)	0.622	33 (75.0)	2.00 (0.91–4.38)	0.083	42 (63.6)	1.46 (0.84–2.53)	0.178

≤ 60 = Distance below or equal to 60m from marking unit, > 60 = Distance beyond 60m from a marking unit, n=number of recaptured mosquitoes, IRR=Incidence rate ratio, 95%CI = 95% confidence interval

Environmental Data

During the study, a data logger was installed at a mosquito collection site to continuously record temperature and relative humidity. Recorded temperature ranged from 25.4°C to 28.3°C (Fig. 5a), with a mean of 27.3°C, while relative humidity ranged from 65.3% to 91.7% (Fig. 5b), with a mean of 77.5%. Both temperature and relative humidity were within the optimal range for mosquito survival and activity.

Discussion

The present study reports the first recent field-based mark-release-recapture (MRR) assessment of *Ae. aegypti* in Dar es Salaam, the principal dengue hotspot city in Tanzania [46–49]. The overall recapture rate of released mosquitoes was 7.3%, which is comparable to rates reported in similar MRR studies [23, 25, 27, 43, 50–52] that reported less than 10%

recovery rates of released mosquitoes. Such recapture rates, indicate that the experimental design was successful under local field conditions. Both wild and marked mosquitoes were recovered in all directions around the release point (cardinal directions), further suggesting successful mosquito dispersal from the release point and adequate mixing with the natural mosquito population. In a context where vector control remains the primary strategy for managing diseases such as dengue fever, the recapture rate observed in this study highlights the utility of the MMRR method in evaluating the potential effectiveness of release-based mosquito control approaches such as *Wolbachia*-infected mosquitoes, the sterile insect techniques (SIT) programmes, and gene drive-technologies within Tanzanian settings. The study further showed that recapture rate was slightly higher for male mosquitoes than for female, consistent with findings reported by Muir and Kay [53] despite the 50:50 female and male emergence assumption. This pattern may reflect sex-specific behavioural differences, particularly the active mate-searching behaviour notably exhibited by males [54] which could increase their probability of encountering traps.

Understanding *Ae. aegypti* dispersal is a critical aspect for effective application of mosquito release-based control approaches. The effectiveness of these interventions largely depends on dispersal metrics including mean distance travelled (MDT) and maximum distance travelled (MaxDT) by mosquitoes after release. Previous studies have reported MDT value for *Ae. aegypti* ranging from 80m to 110m globally, including in East Africa [36, 55, 56]. In the present study, the MDT was estimated at 94.5m, falling within the reported range, and the MaxDT was 156m. These distances confirm that, *Ae. aegypti* is a short-distance flier in this setting, a behavioural trait that may be advantageous for xeno-monitoring arboviruses during outbreaks [57, 58]. Furthermore, short-distance flight may negatively impact reproductive success by limiting access to oviposition sites [59]. In addition to quarantine and contact tracing, during arboviral outbreaks such as dengue, these dispersal characteristics may allow public health authorities to implement targeted larval sources or release-based control interventions within a limited radius around residences of infected individuals, thereby improving cost-effectiveness.

Insect flight range is influenced by several environmental factors, including landscape structure, building density, vegetation cover, availability of breeding sites, wind, temperature and humidity [56, 60–62]. In this study, the flight range encompassing 90% of the released *Ae. aegypti* population (FR90) was estimated at 107m, indicating that most mosquitoes did not disperse beyond this distance. Consequently, implementing vector control interventions within this radius may effectively target the local mosquito population. Trap type and spatial distribution are known to influence estimated mosquito dispersal distances in MMRR experiments [63]. Medeiros et al. [63] reported that deploying traps closer to the releasing point increases the probability of recapturing the mosquitoes at shorter distance, potentially limiting their dispersal. In the present study, traps were densely deployed within the first and second annuli. This configuration may represent a limitation as mosquitoes may have been recaptured before reaching the farthest distances. Therefore, future studies should consider deploying traps at regular intervals across the full range of distances from the release point to ensure a more even spatial distribution of sampling effort. It worth noting that this recommendation should be made with caution, as a study conducted in Switzerland has reported mosquito recapture even in the outermost annuli despite a lower and uneven distribution of traps [29].

For a mosquito to transmit the pathogen, it must survive long enough to complete the extrinsic incubation period of the pathogen. The optimal EIP of dengue virus ranges between 7 to 12 days [44], meaning that a mosquito must survive at least 7 days after acquiring an infectious blood meal to become capable of transmitting the virus. In the present study, mosquito's average life expectancy was 13.5 days, which results in an average daily survival probability of 0.93. These estimates indicate that a substantial proportion of the mosquito population survives long enough to complete the EIP and therefore could contribute to dengue transmission. The survival analysis further showed that approximately 80% of both male and female *Ae. aegypti* survived up to 10 days, which lies within the reported EIP range of dengue virus [44]. This proportion is epidemiologically important because even a relatively small fraction of long-lived females can disproportionately sustain transmission [64]. Similar survival durations have been reported in other studies for *Ae. aegypti* [36, 65]. With the evidence that *Ae. aegypti* gonotrophic cycle lasts approximately four days [66], therefore, surviving

females could potentially complete at least two cycles before dying, thereby increasing the likelihood of multiple host contacts and consequently increasing virus transmission. These findings underscore the epidemiological relevance of mosquito longevity in sustaining arboviral outbreaks. Moreover, both male and female exhibited similar survival time. The comparable survival patterns observed have operational implications for release-based interventions. For strategies such as *Wolbachia*-infected mosquitoes, SIT and gene drive technologies, released males must survive long enough to successfully compete for mates in the field. The observed survival profile suggests that released intervals must be aligned with both the estimated survival time and the wild population turnover rate. Based on the estimated daily survival probability, release cycles at interval not exceeding 13 days may be necessary to maintain the impact of the control strategies.

Effective suppression of wild mosquito population through release-based approaches depend on accurate estimation of wild male population size and achieving a sufficient overflooding ratio [67, 68]. A minimum ratio of 10:1 (manipulated to wild males) has been proposed for effective suppression [69, 70]. Fisher-Ford [20] and Lincoln-Petersen index [45] models are commonly used to estimate wild mosquito population size. However, these models do not always yield consistent estimates, with the later model tending to overestimate the population size [60], primarily because it assumes that the released mosquitoes are a closed population, unlike the Fisher-Ford method. Garcia et al. [71] demonstrated that the two methods can lead up to 50% discrepancies. In this study, we used Lincoln-Petersen [45] as it is widely applied in MMRR studies [29, 31–33, 35, 36, 42, 43, 71]. The overall population size was estimated to be 26,325, including 13,605 males. Based on the estimates and a 10:1 release ratio assumption, a minimum of 130,000 manipulated male mosquitoes would be required to suppress the estimated wild population in 200m radius. This highlights the logistical and financial scale required for successful population suppression in a densely populated urban settings such as Dar es Salaam city.

Temperature and humidity modulate arboviral transmission dynamics. Temperature directly influences viral replication kinetics within the mosquitoes, affecting infection, dissemination and transmission efficiency of the viruses [65] while humidity affects mosquito survival and dispersal [72]. Higher temperatures are associated with shorter EIP of arboviruses [44, 65]. Modelling studies have indicated that the EIP of dengue virus may decrease to approximately five days when the temperature is 32^0C, whereas cooler temperatures prolong viral development [44]. Similar temperature-dependent dynamics have been reported for other arboviruses, including CHIK, WNV and ZIKV [44]. In the present study, temperatures ranged between 25^0C and 30^0C, with relative humidity consistently above 60% in the study area throughout the study period. These conditions fall within the optimal range for both *Aedes* mosquito survival and dengue virus development. Therefore, this climatic profile in Dar es Salaam likely contributes to sustained dengue transmission and may partly explain the relatively higher frequency of dengue outbreaks in the city [73] as compared to other regions of the country [47].

Limitations

The distances between the marking unit and the recapture points of the mosquitoes showed a very high variability with no clear pattern (Fig. 1). Furthermore, the number of recaptured mosquitoes was very low even after aggregating the samples by traps (28 female and 38 male mosquitoes). Hence it was not possible to fit the Weibull survival curve to calculate the FR for female and male mosquitoes separately as well as by trap. The descriptive analysis however suggests that both sexes fly about the same distances (Table 2).

Similarly, the age distribution of recaptured mosquitoes showed a very high variability (Fig. 4). From the small dataset, it was hence not possible to fit the normal distribution to calculate the ALE as well as PDS for each sex separately. However, the descriptive analysis suggests that the male mosquitoes have a slightly higher life expectancy than the female mosquitoes (Table 2). Therefore, estimates accounting for sex differences in life expectancy of *Ae. aegypti* would require studies with much higher number of marked and released mosquitoes.

The analysis for the ALE with the method described in this paper assumes that the dispersal distribution of mosquitoes is approximately normal. This is a reasonable assumption in areas with abundant food sources, where the olfactory and visual stimuli are homogeneously distributed, which is likely in a densely populated study site such as in the city of Dar es Salaam.

Furthermore, traps were densely deployed within the first and second annuli, a configuration that may have limited dispersal, as mosquitoes may have been recaptured before reaching the farthest distances. Moreover, mosquito collections were restricted to outdoor sampling only, household owners' refusal to indoor collections was the reason behind that. This may have limited the accurate estimation of the number of marked mosquitoes dispersing to the respective houses.

Conclusion

This study demonstrated that, *Ae. aegypti* in Dar es Salaam is a short-distance flier, with dispersal largely restricted to within 150 meters. This behavioral characteristic can strategically be leveraged for targeted xeno-monitoring and focal vector control, particularly during dengue outbreaks, by allowing interventions to be concentrated within defined transmission hotspots in addition to the outbreak response measures such as quarantine and contact tracking. The study further shows that mark-release-recapture (MRR) studies are feasible in this setting and can provide useful estimates for mosquito releases strategies. Also, the observed survival duration exceeded the minimum EIP of dengue virus, indicating that a substantial proportion of the vector population survives long enough to sustain transmission, thereby reinforcing the *Ae. aegypti* capacity to effectively transmit arboviral diseases, particularly dengue fever.

Method

Study site

This study was conducted in the Kinondoni district of Dar es Salaam, as described by Tenywa et al. [74]. The district is located at 6.7^{o}S and 39.1^{o}E, covering an area of 269.5 km^{2} and comprising 20 administrative wards. Based on two years of longitudinal survey data on *Ae. aegypti* mosquito, Kijitonyama ward was selected for this study, as it showed a higher density of *Ae. aegypti* than other wards in the district (Tenywa et al. in preparation). This study was conducted from mid-June to mid-July 2024. This period falls just after the rainy season; therefore, most mosquito breeding sites remain available while the absence of rainfall minimizes the risk of colour pigment washout from the marking unit or fluorescent-marked mosquitoes. To assess impact of environmental conditions, one data logger was placed in the study area to record temperature and humidity throughout the experiments.

Mosquito for self-marking experiments

The mosquitoes used for this study were obtained from larvae collected at the same study site. Potential breeding sites for *Aedes* mosquitoes such as garages with discarded tires, garden pots and abandoned water storage containers were identified and inspected for the presence of water. Those containers without water were filled to encourage oviposition. Every day a team of technicians visited potential breeding sites and checked for presence of larvae. If the breeding site was positive for larvae, the larvae along with their water were collected into a 10 liters bucket and transported to the field station. At the station, all larvae were sieved and transferred into plastic bowls used for rearing larvae at the Ifakara Health Institute Bagamoyo (IHI-Bagamoyo) insectary containing the water where larvae were collected at a density of 300–500 larvae per bowl and fed with cat biscuits (Whiskas, South Africa). At the third and fourth larvae instars, they were morphologically identified to species level using taxonomic keys [75, 76] and transferred into bowls with clean water, at a density of 250 larvae. The following day, pupae from each bowl were transported to the field site where the self-marking unit was stationed.

Mosquito self-making

The flight range of *Ae. aegypti* mosquitoes was investigated using a self-mosquito marking unit [32]. Briefly, the marking unit consisted of three parts: (i) a marking grid cloth impregnated with fluorescent pigment, (ii) a rectangular metal frame fitted with male Velcro, and (iii) black cloth panels sewn with female Velcro. The black cloth panels were attached to all sides of rectangular frame by sticking the male and female Velcro, while the marking grid was placed on top of the frame (Fig. 6). To ensure that no emerging mosquito could escape through any opening other than marking grid, a plastic sheet was wrapped around the black cloth panels of the marking unit (Fig. 6). A bowl containing *Ae. aegypti* pupae was placed underneath the making unit and left for 24 hours, allowing the emerging mosquitoes to escape only through the marking grid where they acquired fluorescent powder. In order to determine the exact number of mosquitoes that emerged and escaped, the number of unmerged pupae and dead mosquitoes were counted and subtracted from the total number of pupae introduced in the marking unit. To assess mosquito age structure, four marking grids impregnated with different fluorescent colours (red, green, yellow and pink Wtrcsv, Shenzhen Guang Chen Technology Co., China) [31] were used. Each grid was replaced with a new colour every one day after deployment.

Mosquito recapture

Mosquito collections were carried out for 21 days following the first marking, within 250m radius of the marking unit (Fig. 7). Four different mosquito collection methods were used: (i) Biogents (BG) Sentinel Trap (Bioagents, Regensburg, Germany) targeting host-seeking mosquitoes (ii) resting buckets locally made (iii) Prokopack aspirator (John W Hock Company, Gainesville, FL, USA) for resting mosquitoes and (iv) locally made Gravid *Aedes* Traps (GAT) [77] targeting ovipositing mosquitoes. The collections were conducted in 14 randomly selected houses where all four trapping methods were employed. Prior to trap deployment, a team of technicians visited the household and requested permission to collect the mosquitoes from the household head through informed consent form. Once consent was obtained, the geographic coordinates of the particular house were recorded and the traps were deployed outdoors for 24 hours. After 24 hours, a team of technicians, visited the household and requested the household member for the permission to assess the traps for mosquito presence. The collection of trapped mosquitoes started with the bucket first, followed by those around the house using Prockopack aspirator, and thereafter in GATs and BG traps. The collected mosquitoes were placed in a cooler box and transported to the field station, where they were morphologically identified to species level [78]. All *Ae. aegypti* specimens were examined for the fluorescent pigment marking using a UV-light torch and microscope.

Data management and analysis

All data were initially collected on hard copy forms and later entered into excel. The data were then cleaned using STATA package version 17 (Stata Corp, College Station, TX). Data analysis for the MDT, ALE and FR were performed using R software and the respective figures were plotted using the ggplot package in QGIS. The formula for the ALE and the FR were fitted using a STAN script.

Marked mosquitoes

A descriptive analysis was conducted to determine the number of marked-emerged mosquitoes from a marking unit relative to the total released. This was calculated by subtracting the number of dead pupae and adult mosquitoes in a marking unit from the total number of pupae initially placed under it.

Mosquito Dispersion

Dispersion patterns were assessed using three parameters: Mean Distance Travelled (MDT), flight range (FR), and Maximum Distance Travelled (MaxDT), following Morris *et al*. [22]. The MDT was calculated as described by Lillie *et al*. [81] by including a collection factor to account for difference in trapping effort across distances. The sampling area was divided into four annuli, each 60m wide (Fig. 7b). The annulus correction factor (CF) was calculated as the total number of

traps multiplied by the proportion of the annulus area relative to the total trapping area. The estimated recaptures (ER) per annulus were computed by multiplying the CF by the proportion of observed recaptures and the number of traps in that annulus. MDT was obtained as the summation of the products of annulus ER and annulus distance, divided by the total number of ER.

Due to the small study area and the need to consider all the traps that did not catch any mosquitoes, there are only three data points for the cumulative ER available. Following the standard approach for the FR as described by Lillie et al. [81] and suggested by Morris et al. [22] hence yielded unreasonable, massive confidence intervals. A different method to calculate the flight range was therefore used. As in Smith et al 2026 [82] the final dispersal of the mosquitoes from their emergence point at the marking unit was assumed to be normal distributed with mean 0. Similar to the calculation of the ALE, the variability of recaptured mosquito was assumed to follow a Poisson distribution. To estimate the standard deviation of the normal distribution, the number of recaptures for each distance n(x) was fitted to a Poisson distribution over the normal dispersal kernel as shown in the formula below.

$$D\left(x\right) \; = \; \frac{C}{\sqrt{2\pi\,\sigma^{\,2}}}\; exp(-\frac{x^2}{2\sigma^{\;2}})$$

$$n\left(x\right) \; \sim \; Poisson\left(D(\,x\,)\right)$$

Where:

x = Distance

σ = Standard deviation

C = Scaling constant for the total amount of mosquitoes

D = Distribution of mosquitoes by distance

n = Number of mosquitoes by distance

The FR50 and FR90, in which 50% and 90% of mosquitoes travelled respectively, was then calculated by intersecting the resulting distribution at 0.5 and 0.1 (Fig. 2).

MaxDT was defined as the furthest distance at which marked mosquitoes were collected as introduced by Vavassori *et al*. [29].

Average life expectancy and survival rate

The standard approach given by Niebylski and Craig [83] assumes an exponential decline in the number of mosquitoes over time. However, the age distribution in our data is a step function (Fig. 4), with approximately age-independent numbers of recaptures until about day 13. In after which, no more mosquitoes where caught. Therefore, a different method to calculate the average life expectancy was applied, where the survival of mosquitoes was assumed to be Weibull distributed with the percentage of mosquitoes dying up to day t given by the cumulative distribution function (cdf) of the Weibull probability distribution function. The percentage of mosquitoes still living at day t was hence given by 1-cdf. This function was scaled by a constant C to fit for the total number of mosquitoes, and number of mosquitoes caught was then determined by a Poisson distribution over the number of surviving mosquitoes. This results in the formula below.

$$S\left(t\right) \; = \; Cexp(-(\frac{t}{\lambda})^{\kappa}\;)$$

$$n\left(t\right) \; \sim \; Poisson\left(S(\,t\,)\right)$$

Where:

t = Time (days)

κ = Shape parameter

λ = Scale parameter

C = Scaling constnat for the size of the population

S = Survival of mosquitoes by time

n = Number of mosquitoes by time

The average life expectancy (ALE) was then calculated by extracting the median survival, and the average probability of daily survival (PDS) over all days by the formula below.

$$PDS = exp(-\frac{1}{ALE})$$

Population size

Mosquito population size was estimated using the Lincoln Index [45] under the assumption that the marked mosquitoes mix homogeneously with the wild population, there is no immigration to or emigration from the sampling area, and mortality is constant between marked and wild mosquitoes. The population size was calculated by the formula given below.

$$P = nm/r$$

Where:

P = Population size

n = Total captured mosquitoes

m = Marked released mosquitoes

r = Marked recaptured mosquitoes

Declarations

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Authors' Contributions

Conceptualisation: FSCT and SJM; Data curation: FSCT, OD, MH, and HM; Formal analysis: FSCT, LNF, NC and TAS; Investigation: FSCT, OD, MH, HM and JM; Methodology: FSCT and SJM; Supervision; SJM; Writing original draft: FSCT and LNF; Visualization: SJM, NC, TAS and LNF; Writing review and editing SJM, NC, TAS and LNF; Funding acquisition: SJM. All authors read and approved the final manuscript draft. The authors declare that ChatGPT was used by FSCT to improve syntax of the manuscript draft.

Availability of data and materials

The datasets generated during the study are available from Ifakara Health Institute and are freely accessible on open depository https://osf.io/2x359/overview

Additional information

Competing interests

The authors declare no competing interests.

Ethics approval

This study received an ethical approval from the Ifakara Health Institute Review Board (IHI-IRB) IHI/IRB/No: 7-2021 and National Institute for Medical Research Review Board (NIMR-RB) No. NIMR/HQ/R.8a/Vol. IX/3641.

Consent for publication

All authors contributed to the manuscript and approved the final manuscript. The permission to publish was provided by the National Institute for Medical Research Review Board (NIMR-RB) Ref No. BD.242/437/01C/196

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Figures

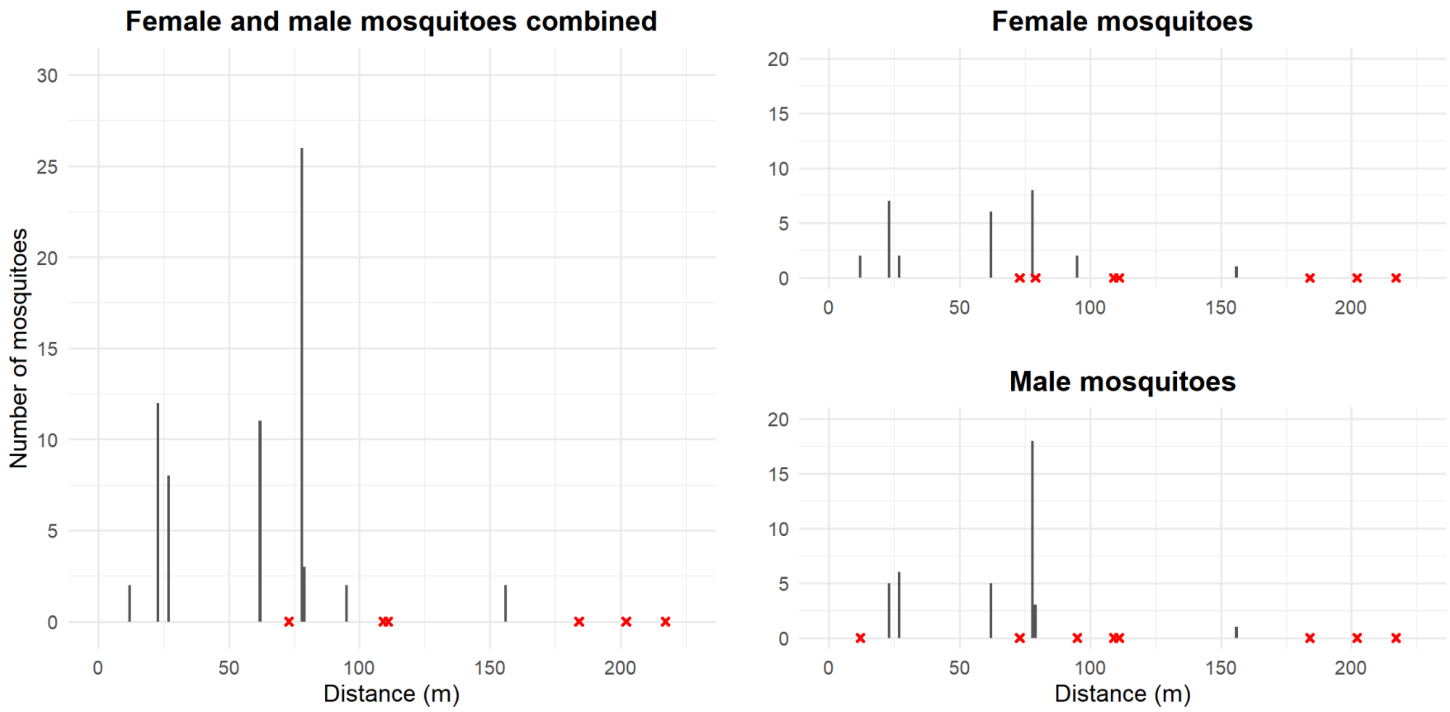


Figure 1

Aedes aegypti flight distance from the marking unit. The red crosses denote distances where traps were deployed but no mosquito was recaptured.

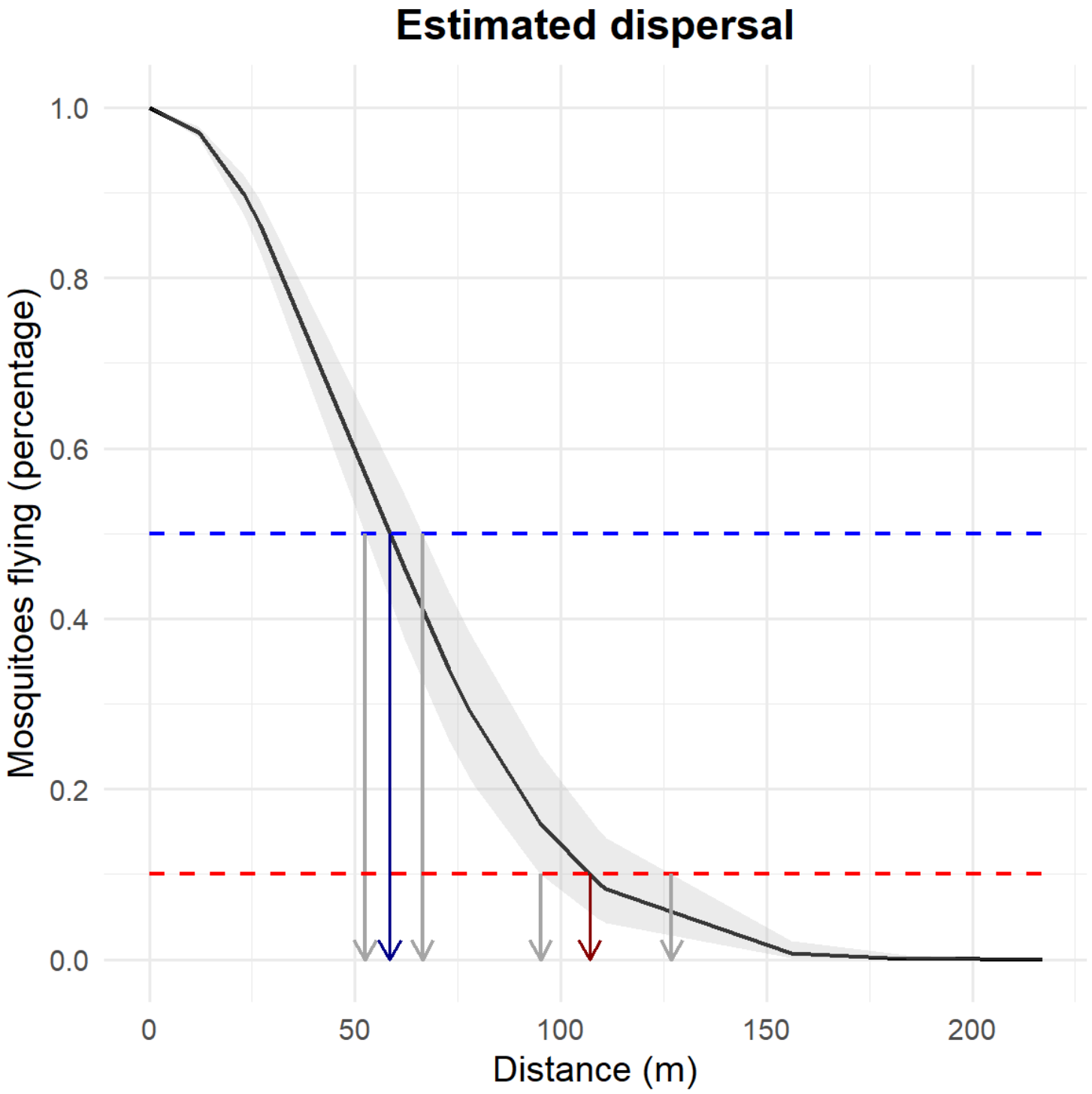


Figure 2

Estimated dispersal of the recaptured *Ae. aegypti* to calculate the flight range (FR). The blue dashed line denotes the cutoff where 50% of the mosquitoes would fly, while the red dashed line shows distance at which 90% of the mosquitoes are expected to fly. The blue and maroon arrows denote the flight ranges (FRs) while the gray arrows indicate the confidence intervals for each FR. (https://osf.io/2x359/overview)

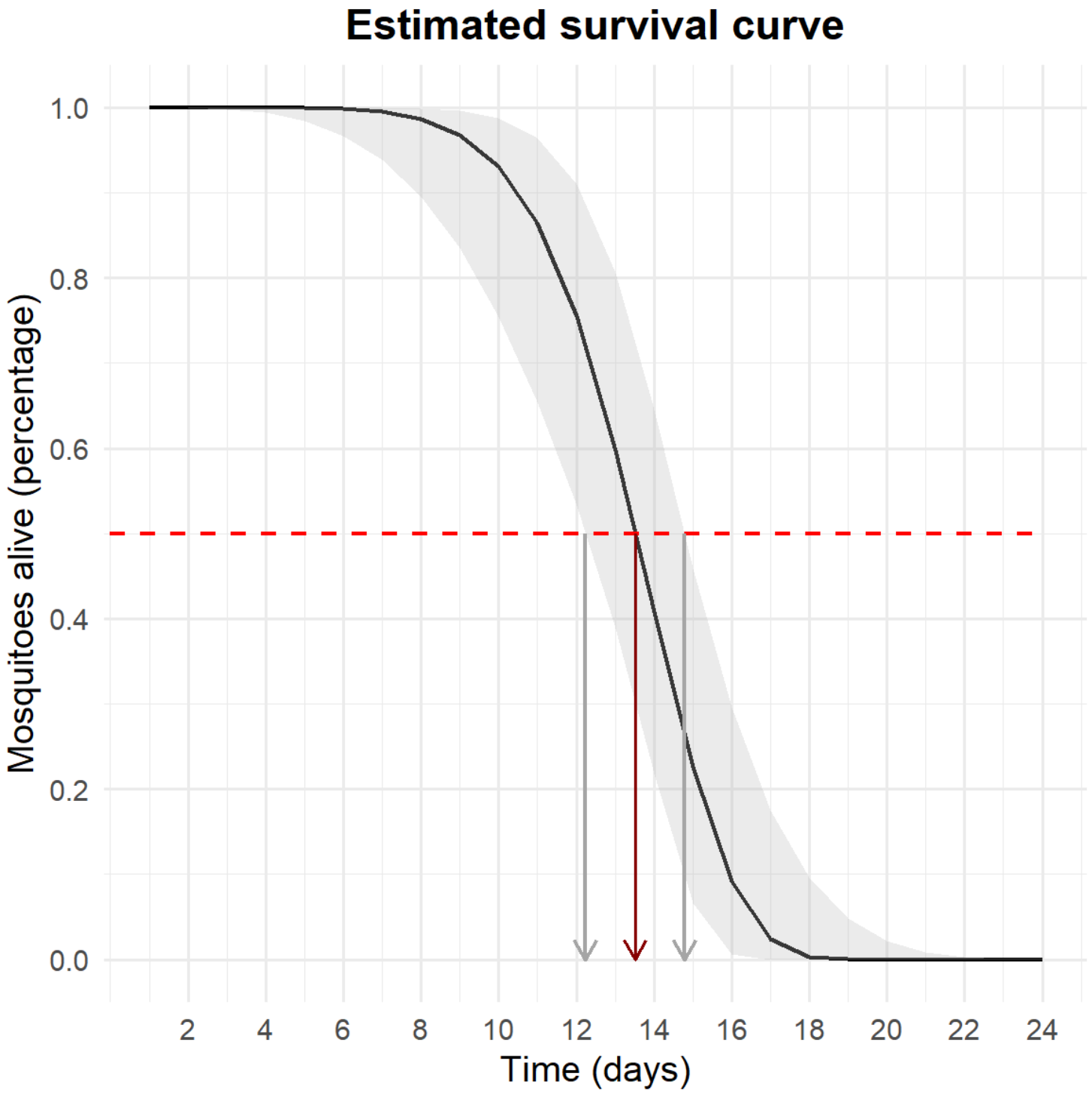


Figure 3

Estimated survival curve to calculate the average life expectancy (ALE) of *Ae. aegypti.* The doted red line indicates 50% of alive marked mosquitoes while the maroon and gray arrows show the average life expectancy and 95% confidence intervals respectively. (https://osf.io/2x359/overview)

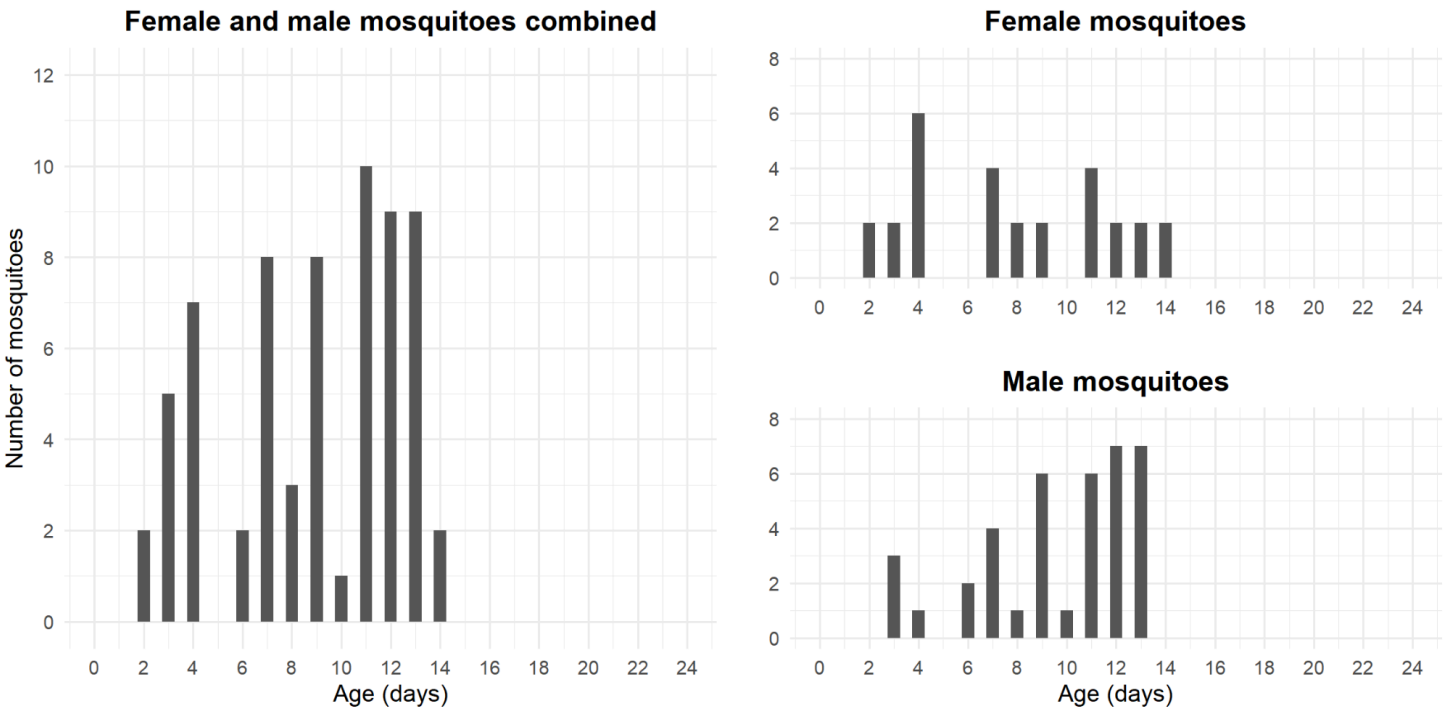


Figure 4

Age distribution of recaptured *Aedes aegypti* post emergence.

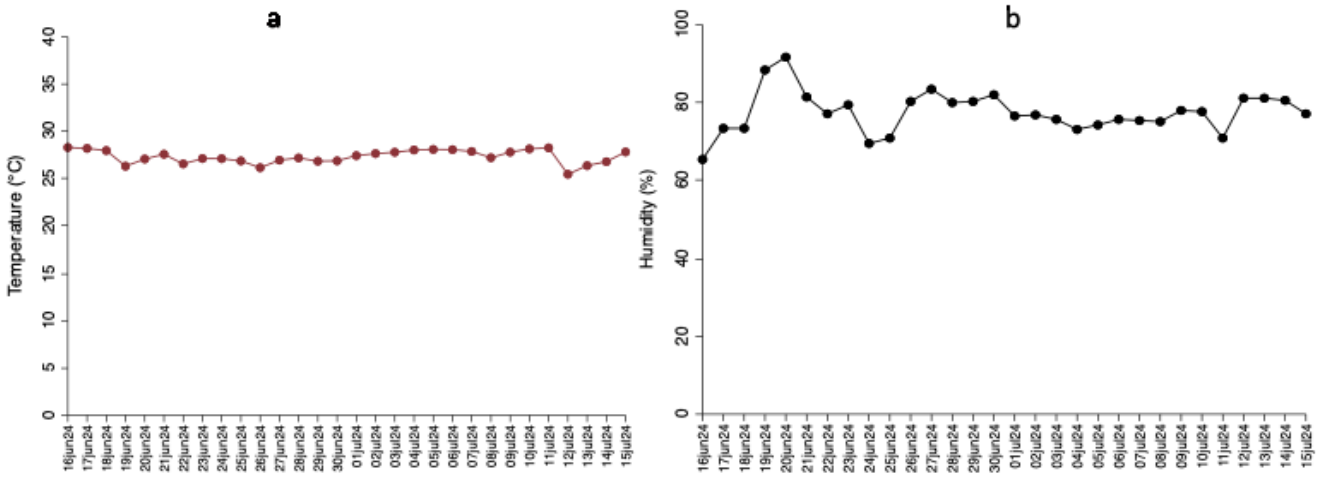


Figure 5

Weather conditions monitored during the experimental period



Figure 6

Mosquito self-marking units with fluorescently impregnated grid cloths to distinguish mosquitoes by emergence day.

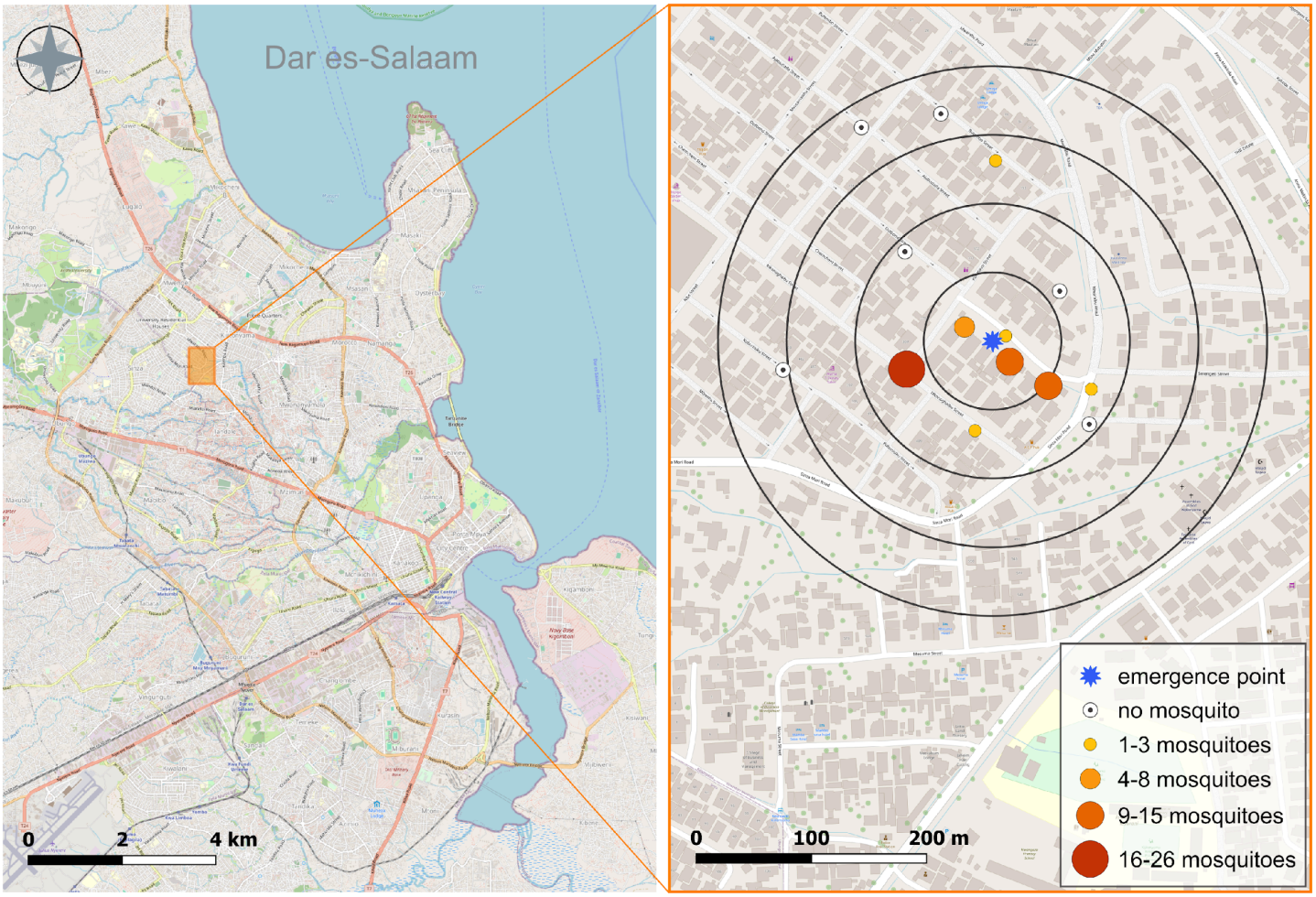


Figure 7

a) Map showing the location of the mosquito mark-release-recapture study site in Kinondoni district, Dar es Salaam **b)** Location of the self-marking unit and spatial distribution of mosquito traps. A blue marker indicates where the self-marking unit was placed. Yellow markers ranging from faint to deep, represent locations where mosquitoes were recaptured. Grey markers indicate points where no mosquito was recaptured. The black circles represent annuli at 60m apart. Base maps were provided by Open Street Map Contributors [79] through the QGIS plugin [80]. Map data copyrighted by OpenStreetMap contributors are available from https://www.openstreet map.org