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The Furvela tent-trap Mk 1.1 for the collection of outdoor biting mosquitoes

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Outdoor transmission of malaria and other vector borne diseases remains a problem. Suitable methods for assessing vector density are required and a number of tent-traps, for the collection for outdoor biting mosquitoes, have recently been developed. Only one such trap, the Furvela tent-trap, does not require an ‘entry’ behavior on the part of the mosquito. It remains the cheapest and lightest tent-trap described. It takes less than two minutes to install and is the only trap described that uses readily available components. We also describe recent modifications to the trap, which make it even easier to set up, provide an SOP and describe some recent experiments examining the effect of the addition of light to the trap. We also provide a short review of work so far undertaken with the trap in Mozambique, Ghana and Tanzania. The trap provides the closest approximation to CDC light-traps, widely used to collect indoor biting mosquitoes. This enables the effect of a number of interventions on mosquito density and indoor/outdoor behaviors to be determined.
The Furvela tent-trap Mk 1.1 for the collection of outdoor biting mosquitoes

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With the current drive to eliminate malaria, worldwide reductions in the burden of the disease have occurred (Bhatt et al., 2015). This success has highlighted the challenges that remain and spurred the development of novel control methods, in particular, odour-baited traps, that target outdoor biting mosquitoes (Okumu et al., 2010a, b). As pointed out by Kiware \textit{et al.}, (2012), the development and implantation of these novel techniques will require a ‘vastly improved understanding of the ecology of mosquitoes generally’. Although it is the malaria vectors that are of primary concern, many other outdoor biting mosquitoes are potential vectors of pathogens, among which are a number of ‘emerging’ or potential diseases. Much of the work that has previously been done on the ecology of outdoor biting
mosquitoes, notably the studies of Gillies and Wilkes (1969, 1970, 1972) have sampled the mosquitoes in ways that do not easily translate into estimates of outdoor exposure, a prerequisite of understanding the effects of such novel interventions. Outdoor exposure is best measured in human landing collections (HLC), in which mosquitoes are caught attempting to bite the exposed lower legs of collectors sitting outside, since sitting outside is what people are doing anyway. They have been used extensively in the past, largely just to sample malaria vectors. Landing collections impose risks to the collectors, however, and risk-free collection methods are required. Indeed the World Health Organization (WHO, 2014) recently recognized the necessity for novel sampling tools to conduct entomological surveillance outdoors. The objective of such surveillance would be to assess vector species composition, abundance, and the time and place of biting. The primary requisites of such methods are that they catch mosquitoes that would normally bite outside and that the numbers caught should be comparable with landing collections. Something simple and inexpensive is also desirable.

Commercially available Centre for Disease Control (CDC) light-traps have been used in a number of studies due to their being risk-free, widely available and cheap to run (Githeko et al., 1994, Constantini et al., 1998, Cooke et al., 2015). Whilst operationally practical, evidence from these studies suggests that, at least as far as malaria vectors go, they do not adequately sample the outdoor biting fraction of the population (Fornadel, Norris and Norris, 2010). Thus, Costantini et al., (1998) reported no significant correlation between outdoor HLC and outdoor CDC light-traps in the case of An. gambiae s.l. and density-dependent correlation in the case of An. funestus. Cooke et al. (2015) attempted to measure
the outdoor biting fraction of the population by employing a CDC light-trap hung adjacent
to an occupied, open-sided rain shelter constructed from a domed one-man tent but
concluded that such traps were a ‘limitation’ of their study. Other traps, notably the MM-X
trap (Njiru et al., 2006) have been developed to catch outdoor biting populations of
mosquitoes but they do not provide an easily quantifiable estimate of exposure, nor are
they cheap or easily available.

Tent-traps are the simplest alternative solution. DeMeillon (1934) first used tent-traps to
collect *An. gambiae* in South Africa. He used a plastic gazebo tall enough to allow people to
stand inside it. It had openings cut close to the roof that mimicked the eaves in a house.
Collectors stood inside the gazebo (their breath and odour attracting mosquitoes) and
collected them off the inside walls when the insects were inter-current resting (Mattingly,
1965). Thus, this was more akin to a moveable experimental hut than a trap for collecting
outdoor biting mosquitoes.

More recently a number of other tent-traps have been developed (Charlwood, 2005,
Govella et al., 2009, Krajacich et al. 2014). All but one, however, are similar to the gazebo of
DeMeillon (1934) in that they require an ‘entry’ behaviour on the part of the mosquitoes
for them to be caught. The usefulness of these ‘other’ tent-traps is undetermined because
not all mosquitoes go inside houses and, as pointed out by Gillies (1974) ‘the effectiveness
of a baited trap for a particular species of fly primarily depends on its responses to the
trapping device in the presence of the attractant stimuli used’.

One trap, the, so-called ‘Furvela’ tent-trap, however, does not require such an entry
behaviour from the mosquito and hence is more likely to sample the ‘true’ outdoor fraction
of the population. Mosquitoes are instead collected by a battery-operated CDC light-trap
placed horizontally on the outside of the tent 4cms from an opening approximately the size of the diameter of the trap body in the tent door. In addition, the Furvela tent-trap remains the most straightforward, lightest and cheapest tent-trap available. It is the only trap that is made from available ‘off the shelf’ components, including the tent itself. Collections in the Furvela tent-trap are closely correlated to CDC light-trap collections used to monitor indoor biting mosquitoes (Govella et al., 2009, Charlwood et al., 2011, 2012). This makes it especially useful for the measurement of changes in indoor/outdoor ratios following the application of methods to control indoor biting mosquitoes. Recently it has been used as the delivery system and monitoring tool in the evaluation of an intervention that targets outdoor biting mosquitoes in Cambodia (Charlwood et al., 2016).

A number of small modifications to the original design have been made. These make it even easier to set up in the field, but do not affect its basic operation. Here we describe these modifications, discuss some recent experiments to examine the effect that the addition of a light to the trap has on numbers caught and provide a short review of work so far performed with the trap from Africa. We also provide a Standard Operating Procedure (SOP) on how to set the trap up in the field.

The Furvela tent-trap Mk 1.1

Recent improvements to the original description include the following (Fig 1 A-F):

A.  *The opening is more easily standardized.* For this the sides of the tent are sewn back rather than being folded back by clips (although clips can still serve). We have occasionally found people who do not trust in the traps efficacy and so
close the tent, which negates the trap. In addition to standardizing the opening sewing it makes it more difficult for the tent to be zipped up.

B. **Attaching the trap is easier.** A small hole is made, using hot wire, in the Perspex close to the top of the CDC trap. Short (6-7 cm) lengths of the same wire are threaded through these holes and medium sized folding-clips attached. The clips are used to attach the trap to the tent.

C. **A cover over the collection bag allows collections to continue in the rain.** The collection bag has a rain cover (that attaches to the body of the trap with Velcro or a rubber band) sewn over the top half of the net.

D. **Supporting the collection bag is easier.** Two eyelets are sewn into it the bottom of the bag to facilitate attachment.

E. **An external support for the collection bag is no longer required.** The bag is now supported in place by two guy ropes, thus eliminating the need for an external support for the bag. Some tents (e.g. the Hoolie Wildcountry) already have these guy ropes available. They generally are otherwise not difficult to attach to other tents

F. **A footprint makes life easier.** Although not mandatory we find that a plastic sheet (‘footprint’) under the tent and up to the edge of the collection bag makes life easier, prevents holes in the bottom of the tent and may reduce exposure of the collected mosquitoes to ants.

The Standard Operating Procedures (SOP), (supplementary file 1), shows these modifications in more detail. The installation of the trap can be seen in the video: https://www.youtube.com/watch?v=irgBPrDQ2Pw. When not in use as a tent-trap
the CDC trap can be easily be reconverted to a standard light-trap without the need to remove the clips (which hang outside of the trap body) and one can go on a camping holiday with the tent.

The Furvela tent-trap – Recent Studies

Methods

The effect of a light source on the density of mosquitoes captured was investigated in a series of collections using four tent-traps from Muleba, Tanzania (supplementary file 2). We used 2-door tents for these experiments (the Highlander Glen Orchy 2 Tent ®). A standard tent-trap functioned as a control on one side of the tent while the trap on the other door incorporated an incandescent bulb, as used in the CDC light-trap. The trap with the light was rotated between sides on alternate days. Tent-traps were operated from 21:00h-0630h the following day and were operated from June 30-July 4, 2014.

The number of mosquitoes collected when the tent has a door at the side or the front was also investigated in Muleba. The tents used were also the two-door Glenn Orchy Highlander and the Taurus Ultra-light two-man tent (with a single door at the front of the tent). Collectors rotated between tents on alternate nights and the tents were rotated every second day.

Exit window-traps, like CDC light-traps, are a proxy for exposure indoors. The number of mosquitoes collected from a Furvela tent-trap operated twice a week and window-trap collections collected on a daily basis from a house 10m distant, were compared over a nine-week period. Mean numbers per ISO week were compared (supplementary file 3).
Since changing the collection bag is easy with the Furvela tent-trap it is also possible to examine the biting profile of the mosquitoes throughout the night. This has been done with *An. coluzzii* in Ghana (Charlwood et al., 2012), *An. funestus* in Mozambique (Kampango, Cuamba and Charlwood, 2010) and most recently *An. gambiae* in Tanzania. In Ghana collections were separated into three hourly groups whilst in the, previously unpublished, studies from Mozambique and Tanzania collections were separated into four hourly periods. Collected mosquitoes from these studies were dissected for age determination according to the protocols of Charlwood et al., (2003). (Supplementary files 4 and 5)

Data was entered into a database and analyzed with Stata 12 (Stata, 2013)

The collections conducted in Muleba, Tanzania were done so as a component of the Pan African Malaria Vector Research Consortium project ‘Evaluation of a novel long lasting insecticidal net and indoor residual spray product, separately and together, against malaria transmitted by pyrethroid resistant mosquitoes’ which received ethical clearance from the ethics review committees of the Kilimanjaro Christian Medical College (certificate number 781 on 16/09/2014), the Tanzanian National Institute for Medical Research (20/08/2014), and the London School of Hygiene and Tropical Medicine (reference 6551 on 24/07/2014). The trial is registered with ClinicalTrials.gov (registration number NCT02288637) on 11/7/2014. Prior to beginning collections, informal sensitization sessions were conducted with village members to explain sampling-related activities. Written informed consent was obtained from all participants who could withdraw from the study at any time should they wish to do so.
Effect of light on numbers collected

A new moon occurred on June 27 and there was little/no ambient illumination during collection dates, providing optimal experimental conditions. 32 collections (standard tent-trap (TT) n=16, and tent-trap+light (TT+L) n=16) were performed. A total of 180 An. gambiae, 104 Mansonia spp., 195 Coquelletidia fuscopennata, 140 Culex spp. were collected over a 4-day period. Data fit a negative binomial distribution (the deviance was greater than the mean). The incident rate ratio (IRR) was used to compare the relative density of mosquitoes sampled by a TT+L to a TT. Variables including collector, collection date, and sampling site were identified as potential confounding factors during univariate analysis and were included in the final regression model. Surprisingly, the TT+L caught significantly fewer Anopheles females than the TT (Adjusted-IRR=0.56, \( P < 0.001 \)) (Table 1).

Effects of door position on numbers collected

The rate ratio of the total number of Anopheles captured [IRR 1.05, 95% CI (0.52 – 2.12), \( P=0.9 \)] after 16 collections was not significantly different between the tents, when differences in host attractiveness are accounted for. The IRR of the total number of all mosquitoes captured [IRR 0.92, (95% C.I. 0.50 – 1.68), \( P=0.77 \)] was also not significantly different between the tents, when differences in host attractiveness are accounted for.

Indoor outdoor ratios: Window traps versus Furvela tent-trap

Between the 23/10/2014 and 14/3/2015 70 collections were undertaken from the window trap (only two collections being undertaken in December) and 17 tent trap
collections were performed. Mean numbers per collection were estimated per ISO week and compared between collections. Changes in population density obtained from the two collection methods were similar ($r = 0.93$, $P = 0.0003$) (Fig 2). Immediately following the application of the indoor intervention, insecticide residual spraying (IRS) of primephos methyl and installation of a long-lasting insecticidal net (LLIN) incorporating permethrin and the synergist piperonyl butoxide in the bedroom of the house, the number in the window-trap fell to zero but numbers in the tent-trap persisted, albeit at a very low density.

The Furvela tent-trap – Published Studies

Assessment of survival rates

In Ghana 2119 of 3133 (68%) *An. gambiae* had survived until the morning and more recently, in Tanzania, 1744 of 3089 (56%) *An. gambiae* s.l. survived until the morning (compared to fewer than 3% that survived in light trap collections). There is a bias towards recently emerged insects among live insects (Charlwood et al., 2011). This may be because these insects are more likely to sugar feed (and so survive) rather than any intrinsic advantage (Charlwood et al., 1998), and so in order to obtain unbiased estimates of survival dead insects should also be examined if possible. Survival rates among the exophagic mosquito species collected were significantly lower than among malaria vectors or the *Cx. sp* (mostly *Cx. quinquefasciatus*) collected (Table 2).
Rainfall and its effect on indoor/outdoor ratios

Since they are waterproof, tent-traps can be run in the rain without discomfort. In Okyereko, a rice growing area in the Gold Coast, Ghana, on rainy nights, although the total
An. coluzzii (aka Anopheles gambiae M form) collected in a tent-trap and light-trap pair was
as expected, fewer mosquitoes were caught in the tent-trap than expected and more in the
light-trap (Fig. 3). Thus, rainfall will apparently, temporarily, convert a mixed
indoor/outdoor biting population of vectors to one that bites predominantly indoors.

Changes in indoor/outdoor ratios following IRS

The ratio of tent-trap to light-trap collections can also change as a result of human
perturbations including application of a residual insecticide to walls of houses. The
indoor/outdoor ratio of mosquitoes before and after the application of Bendiocarb applied
by the National Malaria Control Program (NMCP) in an independent study to the interior
walls of houses in Massavasse, in southern Mozambique, (redrawn from Charlwood et al.,
2013) is shown for six of the most common species collected (Fig 4).(Supplementary file 6)

In this two year study the village was divided into a series of 16 quadrats, each
approximately 250 x 500 m in size. Tent-trap samples were run each month as close to the
centroid of each quadrat as possible. The house nearest to this position was chosen for
indoor sampling with light-traps. This generally meant that the light-trap collection was
within 30 m of the tent-trap sample. Tent-traps were run from 7 P.M. to daybreak.

Ratios between light-trap and tent-trap collections among the initially endophagic species
(Anopheles funestus and Cx. sp – mainly Cx. quinquefasciatus) were affected by the
intervention but, unsurprisingly, the ratio of the initially exophagic species (such as Ms. 
*africana*) were not. Whether the apparent change from endophagic to exophagic behaviour 
in *An. funestus* following IRS was because the insects entering the house were killed before 
being caught in the light-trap, or because they refrained from entering houses in the first 
place, remains unknown and merits further investigation.

Following the IRS numbers of *An. funestus* (in both light-trap and tent-trap) collections 
decreased. Exophagic, zoophagic mosquitoes, should have been unaffected by the IRS. They, 
however, also declined in the tent-trap collections at this time. The insecticide may have 
been responsible for this decline but as described in Charlwood et al., (2013) the failure of 
people to pay their water bills meant that the fields were no longer being irrigated and, at 
least among the exophagic species, the elimination of breeding sites was the more likely to 
have been responsible for the decline in the population. *Anopheles funestus* also breeds in 
the water used by the exophagic mosquitoes, so they, too, would have been affected by the 
absence of the water. (Supplementary file 7)

**Biting cycle of outdoor mosquitoes**

In Okyereko, Ghana, numbers of unfed *An. coluzzii* (formerly *An. gambiae* M form) females 
peaked in the middle of the night. Part fed and gravid insects, although always few in 
number were, on the other hand, caught in increasing amounts throughout the night (Fig 
5).

The numbers of mosquitoes collected by time of the night was similar for tent-trap and 
light-trap in collections from Furvela, Mozambique (Fig 6 A-C). Numbers of *An. gambiae* 
(formerly known as *An. gambiae* S form) in tent-traps and window traps from Kyamyorwa, 
Muleba, Tanzania differed in that a larger proportion of the catch was caught in the earlier
part of the night in the tent-trap compared to the window-trap (Fig 6D) ($X^2 = 16.8$, $df=3$, $P = 0.01$) although, for both collections, most insects were caught in the middle hours of the night.

In these unpublished studies from Kyamyorwa, in common with other studies comparing indoor and outdoor collections, *An. gambiae* was caught in approximately equal numbers from window-trap and tent-trap whilst known exophagic mosquitoes were caught predominantly in the tent-trap (Fig 7 A-D).

In Furvela, Mozambique, the pattern of activity of *An. funestus*, the predominant malaria vector in the village, caught in tent-traps was followed through one and a half lunar cycles (Kampango et al., 2010) (Fig 8 A-C). Collection bags were changed every four hours. As occurred with *An. farauti* from Papua New Guinea (Charlwood et al., 1986) the greater part of the night biting occurred when moonlight was present. Thus, greatest numbers were collected in the early part of the night when the moon was waxing (Fig 8A), during the middle of the night on nights close to the full moon (Fig 8 B) and in the latter part of the night when the moon rose after midnight (Fig 8 C). On moonless nights activity was distributed evenly through the night (Fig 8 D) (Kampango et al., 2010)

**Age structure of outdoor biting mosquitoes by time of night**

Since most of the mosquitoes in the collection bag are alive in the morning they can be used for other studies on the mosquito, including dissecting them to determine their age (Figure 9 A-C), the caveat being that in order to have an unbiased estimate of age both insects that survive until the morning and those that die in the trap during the night should be dissected.
Among *An. coluzzii* from Okyreko, Ghana (Fig 9 A) and *An. funestus* from Furvela in Mozambique (Fig 9 B) parity rates, determined according to the protocols in Charlwood et al. (2003) decreased (and so risk per bite decreased) throughout the night. Risk per bite was, therefore, greatest when people might be outside in the early evening. In a smaller, previously unpublished, sample of *An. gambiae* from Kyamyorwa, Tanzania, the highest proportion of parous insects were found in the middle third of the night (Fig 9 C). Unfortunately, the age of non-malaria vectors was not examined in these studies.

In Okyereko, Ghana, the proportion of parous *An. coluzzii* with sacs (indicative of recent oviposition) decreased throughout the night (Fig 10 A). Overall numbers of pre-gravid and older age groups collected were similar by period of the night but among the pre-gravid insects the proportion that were virgin increased throughout the night (Fig 10 B).

**Mapping**

The Furvela tent-trap weighs as little as 2.5 kilograms and so is easy to transport. This makes it particularly suitable for mapping studies. The first maps of densities of outdoor biting mosquitoes from an endemic area were produced using data from Furvela tent-traps from Massavasse, Mozambique. (Charlwood et al., 2013) (Fig 11). Massavasse occupies a 1x2km rectangular area in the middle of rice fields. For the study, the village was divided into a grid of 16 rectangular areas and tent-traps run close to the centroid of each of these. Densities were highest towards the edge of the village for all of the species collected irrespective of season. Traps were also run away from the village in the rice fields. For the exophagic species densities were highest away from the village (Table 3).
The long tradition of conducting human landing collections in the study of vectors of malaria is over. In order to determine how much transmission occurs outdoors suitable alternative methods for the collection of mosquitoes are required. The ratios observed between tent-trap and light-trap collections of exophagic and endophagic mosquitoes, from a number of study sites, indicates that the Furvela tent-trap adequately samples outdoor biting mosquitoes. As reported previously the Furvela tent-trap and CDC light-traps collections are well correlated, particularly among members of the *An. gambiae* complex. Window-traps may be a substitute for light-traps. Thus, a pairing of either a CDC light-trap or window-trap to collect endophagic mosquitoes with a Furvela tent-trap to collect exophagic ones enables the effect of environmental perturbations and either outdoor or indoor interventions to be determined. The data obtained to date with the tent-trap confirm that arborvirus vectors like *Mansonia* sp. or *Coquelletida fuscopenata*, bite predominantly, but not exclusively, outdoors. Among malaria vectors *Anopheles funestus* is the most endophagic. They were always caught in light-traps at higher rates compared to tent-traps. The members of the *Anopheles gambiae* complex, being ‘indifferent’ to the location of the host (Gillies and DeMeillon, 1968), tend to be collected in equal numbers in tent and light-traps. With the current efforts to eliminate malaria, mosquito densities may become very low. Enhancing collections may be useful in such situations. The addition of a light to the trap, however, actually reduced the numbers. Chemical lures (including JDC’s old socks) have yet to be tested.

Natural environmental factors such as rainfall, or artificial ones such as IRS, affected the indoor/outdoor ratio of mosquitoes collected. Thus, in Ghana a greater proportion of the
night’s catch of *An. coluzzii* were collected indoors on rainy nights. Although the sample size in these studies was small they reinforced what people on São Tomé Island told JDC about increased biting indoors during rainy nights. Further studies on this aspect of mosquito behaviour are merited since it may be a mixed blessing. On the one hand, it may increase mosquito exposure to control techniques that work indoors (such as LLINs and IRS) but at the same time it may increase peoples’ exposure to potential vectors. It also implies that in studies assessing mosquito population dynamics simultaneous indoor and outdoor collections should be conducted in order to control for this possibility.

Following IRS with Bendiocarb in Massavasse, Mozambique, the indoor/outdoor ratio of previously endophilic *An. funestus* and Cx. sp (mostly *Cx. quinquefasciatus*) became predominantly exophillic. Unfortunately, we do not know if this was because the insects were killed before being caught in the light-trap or because they avoided entering the house in the first place. If tent-traps had not been used the population decline of both species in light-traps might have been attributed to the insecticide, rather than the more probable cause: the failure of people to pay their water bills. The maps produced with data from regular Furvela tent-trap collections in Massavasse indicate that the highest mosquito densities occurred at the edges of the village and, for the exophagic species, away from human habitation. Information such as that obtained from mapping studies may allow estimates of flight range to be obtained. This may enable ‘focused’ control, such as targeting selected water bodies for larval control. They may also help determine how wide a potential *cordon sanitare*, needs to be for it to be successful.
In Furvela, Mozambique, a greater proportion of the nights’ collection of *An. funestus* was caught in tent-traps outdoors when moonlight was present [24]. This is similar to the results of landing collections with *Anopheles farauti* in Papua New Guinea (Charlwood et al., 1986).

A CDC-trap costs 120 US$ and the cone collection bag 18 US$. A 6V 4.5Ah lead acid rechargeable battery, that costs circa 15 US$ and weighs 0.7 kg, can power the trap for a night (see the SOP). Two man tents can weigh less than 1.8 kilos and cost less than 25$. Thus, the total weight of the trap (including the tent) is just over 2 kg (compared to the 20+ kilos of the Ifakara tent-trap) and cost 173 US$. The professionals who might want to monitor mosquitoes are likely to have CDC light-traps and batteries available. In this case the trap would cost 43 US$. It only requires one person to put it up and, since the interior of the tent is not altered in any way, is comfortable for the sleeper. As can be seen in the video it takes just a few minutes to install once the tent itself is up. The ease with which collection bags can be changed means that collections can easily be sub-divided throughout the night. As a routine, they can be changed when local residents enter their houses so that estimates of actual outdoor exposure can be obtained. Since both CDC light-traps and Furvela tent-traps can easily be transported, effective surveillance of both indoor and outdoor biting mosquitoes over considerable areas is possible. Presently they are being used to monitor mosquitoes over 950 sq kms in Muleba Tanzania as part of the PAMVERC Project. When not in use the CDC trap can easily be reconverted to a standard light-trap without the need to remove the clips, which hang outside of the trap (SOP).
Passive monitoring of mosquito populations is providing information on the distribution of endophilic mosquitoes in Europe (Kampen et al., 2015). Presently this is largely restricted to the collection of insects indoors. The use of the Furvela tent-trap need not be confined to the tropics or to professionals. The very simplicity of the trap means that anyone that goes camping can collect, without risk to themselves from local outdoor biting fauna. Using a smartphone, collections can be geo-referenced and the locality photographed. Thus, with a minimum amount of professional resources and data collection, national databases (of such things as bird flu vectors) could be established. Data, and eventually samples, might be sent to a central location (a mosquito abatement office?) where they would be identified and processed (perhaps for arborviruses). Unlike all other tent-traps the extra equipment required by any sleeper is minimal.

Conclusions

Monitoring outdoor biting activity of malaria vectors is an important component of present efforts attempting to eliminate the disease. Our understanding of the ecology of mosquitoes that may be vectors of emerging diseases, other than malaria, is also slight. These mosquitoes will normally be exophagic. The WHO has recently recognized the necessity for novel sampling tools to conduct surveillance of outdoor biting mosquitoes with the objective of assessing vector species composition, time and place of biting, and abundance (WHHO, 2014). Furvela tent-traps are a simple and effective way of collecting these mosquitoes. It is the cheapest and lightest tent-trap available and is the only one that does not require an entry behaviour on the part of the mosquito for them to be caught.
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Figure 1 (on next page)

The Furvela tent-trap Mk 1

A-F. Modifications and installation of the trap (for details see text).
Exit window trap and Furvela tent-trap collections

Exit window trap and Furvela tent-trap collections of An. gambiae s.l. from the village of Kyamyorwa, Muleba District, Kagera Region, Tanzania. The arrow marks the time when the interior walls of the bedroom were sprayed with pirimiphos-methyl (Actellic) at 1g ai per m² (prior to the spray cross-correlation between mean weekly numbers in the window trap and numbers in the tent-trap $r = 0.93$, $p = >0.001$).
Rainstorms and indoor/outdoor ratios of *An. coluzzi*

The effect of rainstorms on indoor/outdoor ratios of *An. coluzzi* from Okyreko, Gold Coast, Ghana. On rainy nights (Black diamonds) more mosquitoes than expected were caught indoors compared to dry nights (Open diamonds). Reprinted with permission from 18
Indoor and outdoor ratios of the principal mosquitoes collected in Massavasse, Chockwe District, Gaza Province, Mozambique, before and after the walls were sprayed with Bendiocarb at 0.4 gm ai m$^2$ A: *Anopheles funestus* ($n$ before spray = 3754, $n$ after spray = 1742), B: Culex spp. - mainly *Cx. quinquefasciatus* ($n$ before = 4267, $n$ after spray = 2208), C: *An. pharoensis* ($n$ before = 2642, $n$ after spray = 2078), D: *An. arabiensis* ($n$ before = 5406, $n$ after spray = 512), E: *Aedes muscides* ($n$ before = 1085, $n$ after spray = 395), F: *Mansonia africana* ($n$ before = 38173, $n$ after spray = 12054). Data from [18]
Before IRS

After IRS

Tent-trap

Light-trap
Figure 5 (on next page)

Number of *An. coluzzi* in Furvela tent-traps by time of the night.

Number of *An. coluzzi* in Furvela tent-traps by time of the night, Okyereko, Gold Coast, Ghana. Reprinted with permission from Charlwood et al., 2011.
Comparisons in numbers caught in CDC light-traps and Furvela tent-traps, by time of the night

A –C Comparisons in numbers caught in CDC light-traps and Furvela tent-traps, by time of the night, Furvela Mozambique A) *An. funestus* B) *Mansonina africana* C) *Ms. uniformis*. D) comparison between window trap and Furvela tent trap, *An. gambiae* s.l. from Kyamyorwa, Muleba District, Tanzania.
**A**

Mean number collected

Period of the night

**B**

Af light

Af tent

**C**

Window

Tent

**D**

uniformis light

uniformis tent
Figure 7 (on next page)

Window-trap tent-trap ratios

A-D. Window-trap tent-trap ratios of four common species of mosquito, Kyamyorwa, Muleba District, Tanzania A: *Anopheles gambiae* B: *An. coustani* C: *Coquelettidia fuscopennata* D: *Manson*ia spp.
Window trap

Tent-trap
Numbers of *An. funestus* caught in tent-traps by time of the night at different phases of the lunar cycle, Furvela Village, Morrumbene District, Inhambane Province, Mozambique. A = waxing, B = full moon, C = waning, D = moonless (redrawn with permission from Kampango et al., 2010)
Mean number collected

Period of the night

Waxing

Waning

Full

No moon

Mean number collected
Figure 9 (on next page)

Parous rates by time of the night

A-C. Parous rates by time of the night - A) *An. coluzzi* from Okyereko, Gold Coast, Ghana (n = 729); B) *An. funestus* from Furvela, Mozambique (n = 426); C) *An. gambiae* from Kyamyorwa, Tanzania (n = 312). (Note: in Okyereko the night was divided into 4 three-hour periods whilst in Furvela and Kyamyorwa it was divided into 3 four-hour periods).
**Figure 10** (on next page)

Proportion of mosquitoes parous or mated by time of the night

A) Proportion of parous *An. coluzzi* from Okyereko, Ghana, with large ovariolar sacs by period of the night (chi square = 6.7, p = 0.08) & B) proportion of ‘first-feeding’ *An. coluzzi* by time of the night according to mated status, (chi square = 31.4, p > 0.001).
Density distributions of mosquitoes collected from Massavasse, Mozambique

Relative density distributions of mosquitoes collected from Massavasse, Mozambique, in tent-traps in the hot season (October to April) and the cool season (May to September). The mosquito density is represented by a sliding colour scale from dark red (highest) via light red - yellow - light green to dark green (lowest). A = *Anopheles funestus*, B = *A. arabiensis*, C = *A. tenebrosus*, D = *Culex quinquefasciatus*, E = *Cx. tritaeniorhynchus*, F = *Mansonía africana* (from Charlwood et al., 2013)
Table 1 (on next page)

Comparison between number of mosquitoes collected between tent-trap and tent-trap with a light source

Comparison between number of mosquitoes collected between TT and TT with light source (an incandescent 6V light as used in a standard CDC light-trap) * Adjusted for collector, location, and date, Kyamyorwa, Muleba, Tanzania
| Method    | Anopheles* | Mansonia sp | Total All Species |
|-----------|------------|-------------|-------------------|
|           | DRR        | Adjusted DRR* | DRR     | Adjusted DRR* | DRR       | Adjusted |
| TT        | 1.0        | 1.0          | 1.0    | 1.0           | 1.0       | 1.0       |
| TT+Light  | 0.24       | 0.14         | 0.56   | 0.52          | 0.47      | 0.38      |
| 95% CI    | 0.08, 0.57 | 0.07, 0.28   | 0.2, 1.6 | 0.27, 0.97   | 0.22, 1.02 | 0.24, 0.59 |
| \(P\)-value | **0.002** | **<0.001**  | 0.28   | **0.04**      | 0.056     | **<0.001** |
Table 2 (on next page)

Survival rate in mosquitoes

Numbers of mosquitoes, by species that remained alive or had died by the end of the night, Kyamyorwa, Tanzania December 2015-January 2016.
|                  | An. gambiae s.l. | An. funestus | An. zeimanni | Cq. fuscopennata | Ms. africana | Ms. uniformis | Cx. sp |
|------------------|------------------|--------------|--------------|-----------------|--------------|---------------|--------|
| Dead             | 1404             | 0            | 20           | 90              | 99           | 94            | 139    |
| Alive            | 1817             | 6            | 9            | 66              | 37           | 22            | 160    |
| % alive          | 56               | 100          | 31           | 38              | 27           | 19            | 54     |
Table 3 (on next page)

Numbers collected by distance

Mean numbers (standard deviation) of mosquitoes collected in tent traps at different distances away from the center of Massavasse village, Chockwe District, Mozambique (from Charlwood et al., 2013)
| Distance to village center (km) | An. *funetsus* | An. *arabiensis* | An. *pharoensis* | An. *squamosus* | An. *tenebrosus* | Ms. *uniformis* | Ms. *africana* | Cx. *tritaeniorhynchus* | Cx. sp |
|-------------------------------|-----------------|------------------|------------------|-----------------|-----------------|----------------|----------------|-----------------------|-------|
| 1.05                          | 9.0 (4.2)       | 5.3 (7.1)        | 1.3 (1.3)        | 0.3 (1.7)       | 3.3 (2.7)       | 70.0 (74.3)   | 703 (462)    | 42.3 (56.4)           | 7.3 (7.7) |
| 0.97                          | 8.9 (7.3)       | 11.1 (10.4)      | 10.4 (12.1)      | 5.9 (6.4)       | 17.9 (42.1)     | 35.6 (56.2)   | 311 (354)    | 32.3 (69.9)           | 9.9 (11.2) |
| 0.61                          | 3.5 (3.9)       | 6.5 (11.2)       | 7.6 (6.3)        | 2.7 (6.5)       | 5.0 (8.5)       | 44.8 (49.3)   | 173 (179)    | 14.5 (17.3)           | 10.0 (11.1) |
| 0.50                          | 9.8 (8.8)       | 6.9 (9.1)        | 3.1 (5.2)        | 3.5 (5.2)       | 9.4 (8.7)       | 30.2 (37.1)   | 140 (210)    | 29.0 (28.3)           | 5.1 (7.9) |
| 0.1                           | 2.4 (3.2)       | 3.0 (7.8)        | 0.4 (0.2)        | 0.2 (0.0)       | 1.4 (7.8)       | 6.5 (5.7)     | 25.1 (34.7)  | 4.1 (5.7)             | 11.9 (13.2) |