Working Material

Limited Distribution

RAF5072

Male mosquito trapping methods

Report of a Technical Meeting held in Vienna, Austria, 16-20 February 2015.

FOREWORD

The sterile insect technique (SIT) package for *Aedes* and *Anopheles* mosquitoes is being developed by the IAEA in response to Member State requests, including equipment and standard operating procedures for mass rearing, stage- and sex-separation and irradiation of males, to support the development of SIT programmes in several Member States. Progress is also being made in the development of a functional release system adapted to the specific requirements of an area-wide integrated pest management (AW-IMP) mosquito suppression programme with an SIT component, with suitable methods for handling and transporting chilled, irradiated male pupae and adults prior to release. It is essential for the efficient running of a release programme that the male mosquito population in the target area is monitored, both in the design phase of the programme to determine the scale of release required, during releases to determine sterile male performance and to tailor releases to real-time population data, and in order to assess the impact of the programme on the vector population. Most mosquito trapping and surveillance technology is aimed at the female vector, whereas the ability to monitor the male population (wild and sterile) is essential for the SIT.

This technical meeting was therefore convened by the Department of Technical Co-operation along with the Insect Pest Control subprogramme of the Joint FAO/IAEA Division of Nuclear Techniques in Food and Agriculture to advise the Member States of the regional Africa project (RAF5072) and others on the available methods and trapping technologies available for male mosquitoes, what is still needed in order to achieve the level of monitoring needed for an AW-IPM programme with an SIT component, and to suggest possible companies or individuals who could develop prototype traps which could be tested in the field. The consultants were selected from research groups currently conducting mosquito population surveillance, and commercial developers with experience in designing and creating devices similar to those which will be needed to trap male mosquitoes, and technologies which may be useful for future developments.

The meeting was held in Vienna from 16-20 February 2015. The authors of this report and IAEA staff members responsible for the meeting are Mr Rafael Argilés Herrero, Mr Jeremie Gilles and Ms Rosemary Lees.

Contents

1. INTRODUCTION

Among the major vectors of human disease agents, mosquitoes are the most devastating ones. Urbanisation, globalisation and climate change have further accelerated the spread and increasing number of outbreaks of new mosquito borne diseases. In view of the problems associated with conventional mosquito control, such as resistance and lack of available vaccines, experts of a Thematic Plan Meeting held in Vienna in June 2014 concluded that there is an urgent need to develop new or complementary control techniques, including the SIT, for major disease-transmitting mosquito species.

The sterile insect technique (SIT) is increasingly being considered as a component of area-wide integrated pest management (AW-IPM) programmes with great potential also for key insect vectors such as mosquitoes. With the increase in vector-borne diseases and their toll on human health and mortality, there have been recurring requests from Member States to develop tools and techniques to be able to apply the SIT to control mosquito vector populations (Resolution GC(58)/RES/18). The SIT has the ability to suppress or in special situations to eradicate existing vector populations and to prevent outbreaks of disease.

The Insect Pest Control (IPC) Section of the Joint FAO/IAEA Division of Nuclear Techniques in Food and Agriculture is involved as part of its programme in the development of the SIT for the suppression or elimination of mosquito disease vectors. Several mosquito SIT pilot programmes are under development in Member States with the assistance of the IAEA and some of these programmes are anticipated soon to reach the stage of operational release of sterile males.

For an effective release programme to be designed, the size and spatial distribution of the target population must be understood, so that releases can be tailored to achieve the desired release ratio relative to the wild male population. These data, in comparison with similar data collected during and after sterile male releases, are essential for monitoring the progress and assessing the success of suppression efforts. Furthermore, possibilities for release by automated GIS systems from the air, potentially by unmanned aerial vehicle (UAV), are being explored. This technology enables insects to be released in a grid system, with frequency of release controlled according to real-time population surveillance data, to maximise effectiveness and efficiency of the releases.

For all these reasons it is important to be able to conduct accurate surveillance of mosquito populations, and particularly wild and sterile male populations in the context of SIT impact monitoring. Since the SIT relies on the release of large numbers of sterile males, one indicator of the efficacy of such programmes and a good surveillance tool would be a means to measure the ratio of sterile males (released and marked) vs. the wild males. Several groups worldwide are involved in such monitoring operations for epidemiological as well as control reasons, but since female mosquitoes are the vectors of disease, trapping and surveillance efforts have mainly been targeted at females.

This technical meeting was, therefore, requested to review current surveillance systems and traps, and those currently in development, for both *Anopheles* and *Aedes*, which will be of use to Member States currently developing programmes for SIT feasibility trials under regional TC project RAF5072, and others. Existing trapping methods were considered for their efficacy and cost-effectiveness for male trapping, and suitable tools for the monitoring of male mosquito population during SIT programmes identified, along with a discussion of considerations and suggestions for how to design and conduct surveillance programmes. Where new technology or techniques are required, the consultants discussed and recommended valuable avenues for further research, identifying partners who may be suitable to help develop and validate traps or methodologies to meet those needs.

2. TECHNICAL REQUIREMENTS FOR MALE MOSQUITO POPULATION SURVEILLANCE

2.1.Overall considerations

National mosquito SIT projects including Sudan (SUD5034), South Africa (SAF5013), Mauritius (MAR5019) and Sri Lanka (SRL5044) are nearing the stage of releasing sterile males for pilot SIT programmes. With the initiation of regional projects RAF5072 and RAS5066, many more countries globally will be working towards implementation of SIT. In all cases surveillance has been conducted over a prolonged period in order to collect baseline population data, to use in the design of releases. However, once releases are started it becomes critical that sufficiently effective surveillance tools and methodologies are available to enable the performance of released males and the impact of releases on the target population to be assessed. In addition, GIS systems are available to help design and implement release distributions targeted to the real-time mosquito population, based on trap data. To take advantage of these advances the ability to effectively monitor population distributions and fluctuations in real time is essential for efficient rearing and release activities. Ovitrapping is a standard method suitable for measuring natural and induced sterility, but methods for adult trapping will also be required. A range of traps are available, particularly for *Aedes* species, but the purpose of this meeting was to assess their effectiveness and suitability for different species, situations and sexes, to advise on the best available techniques, and to identify unmet research and technological needs.

Although many adult traps exist and are used globally for both surveillance and population control of mosquitoes, they were designed for female collection, and so most exclusively or predominantly collect females. Likewise guidelines have been written for mosquito trapping and surveillance (Focks, 2003; Silver and Service, 2008), but male surveillance is not emphasised. While daily survival of males is typically lower than that of females, which would skew the sex ratio of collections, this difference does not often explain the collection disparity. Female population data is important for epidemiological studies, and to monitor a population over time, but for scenarios such as monitoring of survival and dispersal of released males, and especially mark release recapture experiments, it is critical that the traps used are sensitive in collecting males, and new solutions may need to be developed. This may be a matter of producing male specific traps, but may alternatively be a matter of adapting the timing, location or baiting of traps, for example, to target males specifically. For example, the periodicity of male activity is well described in Trinidad and Tobago (Chadee and Gilles, 2014).

The behaviour of males can be exploited for more male-targeted trapping, for example males are seen to circle around traps into which females are more likely to enter more directly, and the addition of a sticky 'wing' to an existing trap may capture these males. Sugar sources, or related floral or fruit scents could be used as male attractants, as could perhaps female acoustic cues, mating pheromones, swarm markers or host cues. It should be noted that the effectiveness of attractants for mosquitoes has been shown to be very variable, and situation specific.

One key aspect of trapping efforts for some purposes, for example where the ratio of released to wild males caught in the traps is being estimated, will be the preservation of the collected individuals in the trap in sufficiently good condition for subsequent analysis between checks of the traps, often one week. The trap design should then allow non-destructive collection and preservation of samples, which will include the protection of the trap from invasion by ants, spiders etc. For example, preserving fluid can be used in wet traps to preserve adults for identification, sticky traps can preserve samples for PCR, or an agent such as an oil which disables wings could be used to prevent adults exiting a trap.

Data from existing trapping programmes can give a very good idea of the relative population size over time, but the accuracy of extrapolation from this data to the scale of magnitude of the real population is unknown. For the design of release programmes the absolute size of the target male population should be known, so that the desired release ratio can be achieved, and the scale of the rearing facility required for the programme can be judged.

Surveillance systems which provide continuous acquisition of systematically collected information which is collated frequently enough that it can be analysed and interpreted to provide operational feedback to the programme managers increases efficient decision-making for SIT programs. There are different surveillance tools currently available with different levels of sensitivity and specificity, and in the future efforts may be required to tailor systems based on the need of the programme. In general the methods or tools should be practical, uniform or standard and rapid rather than 100% accurate or complete (which is impossible). To achieve these objectives the mosquito population should be monitored to:

- Observe changes in abundance in time and space
- In the case of disease outbreaks, estimate abundance in the proximity of infected humans
- Anticipate and take appropriate action, i.e. investigations or control measures

The method normally adopted for these investigations are traps or trapping methodologies. Traps are therefore used as surrogates, e.g. for collecting mosquitoes attracted to man, though direct human-bait collections present a risk due to possible exposure to infectious mosquitoes. Alternatives have to be found to “man-vector contact” (see Achee et al., Vector Borne and Zoonotic Diseases, in press). In SIT systems the collection of male mosquitoes is important to:

a) Identify the scale of the production required

b) Capture males for dispersion and longevity e.g. mark-release-recapture studies

c) Detect the over-flooding male ratio during release

2.2. Suitable methods currently available for mosquito population surveillance

2.2.1. Anopheles adult surveillance tools

The need for traps that can collect male *Anopheles* is more acute than for *Aedes*. The methods for collecting adult anophelines that can be standardized are variable in their sensitivity in different locations, and some potential candidates remain to be assessed. One mainstay – CDC light traps – is widely used but is reported to capture few mosquitoes in many locations. Others, such as the Suna trap or sticky resting boxes could be standardized, but too little experience has been gained to know if they will be useful for many anophelines or males.

Some sensitive methods such as animal baited traps and human landing catches have not been standardized. Methods such as swarm captures are very useful in locations and times when swarms can be located, but this capacity is restricted.

In Table 1, we list several methods and devices that have been used for collecting anophelines with members of the *An. gambiae* complex particularly in mind. We have attempted to evaluate concisely, but admittedly subjectively, the potential for collecting males and other characteristics of each. Note that the summed scores for each trap do not directly lead to a recommendation of the best tools, since each situation will require different characteristics and each criterium will likely be weighted differently.

Characteristic	Resting shelters	CDC light traps	Human landing catch	Human baited traps	Pyrethrum spray catch	House Aspiration	Tree/Vegetation/Barn	Oviposition trap	Suna trap	Sticky resting box	Swarm captures	Animal bait traps	BG Sentinel Trap	MMX
Specificity for target species	2	2	2	2	2	2	2	2	2	2	3	2		
Range of mosquito species collected	2	2	2	2	2	2	3	1			1	3		
Ability to capture target females	3	2	3	3	3	3	3			3	1	3		
Ability to capture target males	3	1	1	1	2	2	3	1			3	1		
Continuous capture	1	3	1	3	2	2	1	3	3	3	1	3	3	3
Condition of collected mosquitoes	3	2	3	3	1	3	3	1	1	1	3	3	2	2
Electricity requirement?	1	2	1	1	1	2	2	1	2	1	1	1	3	3
Amenability to Standardisation	1	3	2	2	2	1	1		3	3	2	2	3	3
Scientific validation	3	3	3	2	3	3	2	1	1	1	2	3		1
Acceptability	2	3	1	2	2	2	3	3	3	2	3	2	2	2
Ease of handling and deployment	1	2	1	1	2	2	3	3	3	3	2	2	2	2
Ease of recovering samples	2	2	2	3	2	3	3	2	2	2	3	2	2	2
Ease of processing samples	3	2	3	3	2	3	3	1	2	1	3	3	2	2
Economical price	2	1	2	2	2	3	2	2	1	2	2	2	1	1
Ease of use	2	1	1	2	2	3	2	2	2	2	3	1	1	1
Availability	3	2	3	2	2	2	3	2	2	2	1	2	2	1

Table 1. Summary table of the tools currently available for surveillance of *Anopheles* mosquitoes, rated according to the most important criteria for trap selection. Higher numbers indicate greater favourability. A summary of characteristics of various trapping methods available for *Anopheles* mosquitoes. "Continuous capture" refers to the characteristic of operating continuously thus accumulating captures. "Acceptability" refers to the expert's assessment of how readily the method is accepted by e.g. homeowners and ethicists. "Ease of use" refers to the degree of burden placed on staff deploying and monitoring the specific trap. Empty cells indicate insufficient data; higher numbers indicate greater favourability.

2.2.2. Aedes surveillance tools

The *Aedes* species being targeted will determine the specific trapping approach. For example, *Aedes aegypti* is primarily found indoors in low numbers requiring more intensive sampling efforts, while *Aedes albopictus* is generally more exophilic. Tables 2 and 3 give a summary of the surveillance tools which are currently available and recommended by the experts as the best available options, scored using the most important criteria so that the most suitable option can be identified for a given situation. Some further details of the operational considerations of the most commonly used tools are also included in this section. Due to the varying reports on trap suitability it is recommended that a pilot study be conducted in each country to determine the efficacy or suitability of the traps and methodology.

Although widely used historically and effectively, there are ethical concerns and issues of standardisation around the use of human landing catches, which will be situation- and culture-specific. The experts point to the report by Achee et al. (in press) published in Vector Borne and Zoonotic Diseases, which offers an authoritative and comprehensive discussion on the subject.

Characteristics	Sweep net (outdoor)	Human landing collections	Aspirator	BG-Sentinel	Passive sticky Gravid traps	GAT	Ovitraps
Range of mosquito species collected	2	1	1	3	1	1	2
Specificity target species	2	3	3	2	3	3	3
Condition of collected mosquitoes	2	2	2	1	1	2	3
Ability to capture female mosquitoes	3	3	3	3	2	2	NA
Ability to capture male mosquitoes	3	3	3	3	1	1	NA
Robustness/reliable	3	3	3	2	3	2	3
Man power to collect samples	1	1	1	3	1	3	3
Man power to process the samples	2	3	3	2	3	3	1
Trap costs	3	3	2	1	3	3	3
Ease of use	3	3	2	3	3	3	2
Scientific Validation	1	3	3	3	2	1	3
Electricity requirement	3	3	2	1	3	3	3
Amenability to Standardisation	2	2	2	3	3	2	3
Acceptability	2	2	2	3	3	3	3
Continuous collection	1	1	1	3	3	3	3

Table 2. Summary table of the tools currently available for surveillance of *Aedes albopictus* mosquitoes, rated according to the most important criteria for trap selection. Higher numbers indicate greater favourability. (GAT= Gravid Aedes Trap).

Characteristics	Sweep net (outdoor)	Human landing collections	Aspirator	BG-Sentinel	Passive sticky Gravid traps	GAT	Ovitraps
Range of mosquito species collected	2	1	1	3	1	1	2
Specificity target species	2	3	3	2	3	3	3
Condition of collected mosquitoes	2	2	2	1	1	2	3
Ability to capture female mosquitoes	3	3	3	3	2	2	NA
Ability to capture male mosquitoes	3	3	3	3	1	1	NA
Robustness/reliable	3	3	3	2	3	2	3
Man power to collect samples	1	1	1	3	1	3	3
Man power to process the samples	2	3	3	2	3	3	1
Trap costs	3	3	2	1	3	3	3
Ease of use	3	3	2	3	3	3	2
Scientific Validation	1	3	3	3	2	1	3
Electricity requirement	3	3	2	1	3	3	3
Standardize-ability	2	2	2	3	3	2	3
Acceptability	2	2	2	3	3	3	3
Continuous collection	1	1	1	3	3	3	3

Table 3. Summary table of the tools currently available for surveillance of *Aedes aegypti* mosquitoes, rated according to the most important criteria for trap selection. Higher numbers indicate greater favourability. NA = not applicable. (GAT= Gravid Aedes Trap).

2.2.2.1. Indoor aspiration

Male and female *Aedes aegypti* are readily captured by aspirating mosquitoes indoors. CDC back-pack and Prokopack electro-mechanical aspirators are commonly used for this purpose. Aspirators are operated as to cover most surfaces inside rooms, particularly in shaded areas such as closets, under beds, behind furniture, etc. Estimating the number of mosquitoes per house should provide a means to extrapolate the total number of mosquitoes in a given urban area (absolute population density). However, it has not been clearly established what percentage of all adult mosquitoes are collected by this means. Therefore, this sampling technique provides estimates of the relative density of *Ae. aegypti*, which can be used to make comparisons among sites or to monitor changes through time. Main disadvantages of this technique are that it is invasive (requires entering houses and having residents' consent), time consuming, labour demanding, and dependent on the skills of the operator. Because the number of adult mosquitoes per house can be highly variable, it is required to sample a relatively large number of houses. For example, the numbers of adult *Ae. aegypti* per room varied from 0-234 in one community but from 0-34 in another community in southern Puerto Rico. In that study, a sample size of 200 houses was considered necessary to provide a reliable estimation (±10-15% error around the mean).

2.2.2.2. BG-Sentinel traps

BG-Sentinel (BG-S) traps have been shown to provide consistent captures of male and female *Ae. aegypti* and *Ae. albopictus*. This is an electro-mechanical trap that has a fan at the bottom of the trap that draws flying mosquitoes into a nylon bag. The trap is collapsible and uses visual and olfactory cues to attract adult mosquitoes. These traps capture adult mosquitoes in most physiological states (nulliparous, parous, blood-fed, and some gravid females). The number of males and females captured per BG-S trap per day were significantly correlated in a study in San Juan, Puerto Rico, although the proportion of males was slightly lower (42%) than that observed in pupal surveys (52%; CDC, unpublished). BG-S traps can be operated with mosquito attractants such as CO_2 and BG-lure or without lures. Modified BG-S traps using black outer covers captured significantly more (~30%) male and female *Ae. aegypti*, higher proportion of positive traps, and more mosquito species than traps with the original white covers. BG-S traps can be operated outdoors and should be placed in shaded, protected areas. Between 20-40 traps should provide a reliable estimation of adult mosquito density (25-35% error around the mean) in a neighbourhood. Traps can be deployed at fixed positions when the main objective is monitoring changes in time.

2.2.2.3. Sticky gravid traps

Several models of passive sticky gravid traps (SGT) have been developed to attract and catch female mosquitoes looking for containers to lay eggs. Captures of female *Ae. aegypti* in autocidal gravid ovitraps such as SGT significantly correlate with captures in ovitraps and BG-S traps. These passive traps (i.e. they do not use power) contain water or a plant infusion to attract ovipositing females. Captures of male *Ae. aegypti* in SGTs are generally small. Sticky traps used for monitoring *Aedes* populations can be checked once a week or less. Specimens are collected using a dissecting needle or forceps and placed on white paper towels for sexing and identification. Some SGTs have been designed so that they do not need frequent servicing. For example, the AGO traps are typically serviced only every two months. The number of traps required for +/- 30% precision is around 20-30 at moderate to high mosquito densities. Trap placement follows the same considerations as those explained before for the BG-S traps.

2.2.2.4. Ovitraps

Ovitraps were designed to detect the presence of *Ae. aegypti* during the eradication campaign in the Americas. Oviposition by *Ae. aegypti* and *Ae. albopictus* can be monitored using ovitraps. Ovitraps are small, dark containers filled with water or plant infusions and a rough substratum where ovipositing females lay their eggs, such as a wood, cloth, or germination paper. Ovitraps are placed in shaded sites away from the rain to avoid egg hatching, which may result if collected eggs are flooded with rainwater. Ovitraps can be checked every week or less. This entails collecting the ovipositing substrate with the eggs, cleaning the container to remove any eggs, and replenishing the water and ovipositing substrate. Because eggs are difficult to identify to species, they are taken to the laboratory for hatching so that identification can be done in the larval or adult stage. The number of ovitraps required to keep precision levels around +/- 30% is 40-90, depending on local mosquito density.

2.2.2.5. Gravid Aedes Trap

The Gravid Aedes Trap (GAT) is a passive ovitrap designed to capture gravid container-inhabiting *Aedes* (e.g., *Ae. aegypti*, *Ae. albopictus*) without the need for messy adhesives

(Eiras et al. 2014, Ritchie et al. 2014). Gravid adults are attracted to plant infusion held within the trap bucket, and then are knocked down and killed by pesticides (residual synthetic pyrethroid spray or a piece of treated bednet) within the translucent trap head. The GAT captured significantly more female *Ae. aegypti* than the MosquiTrap and double the capture of sticky ovitraps (Ritchie et al. 2014); in general it captures less females than a BG-S trap. Dead females are easier to retrieve than those captured on adhesives. However, as the GAT uses insecticide to knock down (KD) females, the trap may not effectively capture pyrethroid resistant mosquitoes, and alternative KD/capture methods should be developed. Captures of male *Ae. aegypti* are generally low (5-10% of the total capture) although occasional high captures suggest that the GAT can be modified to increase capture of males. The GAT has also been used to capture gravid *Ae. albopictus* and *Ae. polynesiensis* (Ritchie and Bossin, unpublished data).

2.2.3. Placement of traps and operational considerations

No specific guidance is offered in this section, as each programme will be different based on the characteristics of the study site and aims of surveillance activities. Further research is needed to develop and test guidelines for designing and performing surveillance programmes in the context of SIT suppression programmes. However, the information below gives a summary of the considerations that are important in the application of traps for mosquito surveillance.

For most purposes, traps should be spaced at distances from each other that reflect the expected dispersal of mosquitoes to avoid spatial auto-correlations that can undermine p-values in statistical analyses. For example, BG-S traps were spaced over 100m from each other in a study of spatial-temporal changes of adult *Ae. aegypti*. When traps are too close together they tend to provide redundant information. However, if the purpose is to observe the dispersal of marked mosquitoes, then traps can be placed closer together to capture their movement in subsequent days. Traps can also be placed closer together when investigating spatial patterns at fine scales (households) or when models that rely on spatial autocorrelations demand it (kriging).

Before release of sterile males, preliminary studies must be made in order to describe the study site and to validate sampling methods and determine appropriate sample sizes. Detailed maps of the site need to be made. This would include up-to-date satellite imagery and house identification (GPS coordinates, streets and address if possible) and, for some species, potential larval and harbourage sites delineated. If multiple sampling methods are considered, Latin Square design trials that rotate treatments between locations can be used to compare captures between different trap types (e.g. Ritchie et al. 2014) for the target mosquito and sex. The logistics of the sampling method (e.g. whether it requires batteries, main power) will also be assessed during this trial. The logistics of sample processing, including the quality of captured material, is also important. This can include the need for fresh or live material for PCR or molecular analysis. Laboratory studies can be used to determine if older specimens can still be successfully processed (e.g. *Wolbachia* can be detected in samples maintained in BG-S (Lee et al., 2012) and GATs (Ritchie et al., 2014). The results can inform the choice used for routine population monitoring. Trap mean and variance can be used to estimate sample sizes.

Baseline sampling can then begin using the appropriate sample method, trap number and location. If the trap is collecting using a continuous method (BG-S, gravid traps), weekly collections are typically used. The interaction between field staff and residents is critical. They will be interacting with residents on a weekly basis, and thus are spokespeople for the programme. Thus, field staff needs to be well briefed on the project and its progress. They can also be in a position to provide brochures and bulletins. Branding of staff with badges and uniforms is an important aspect. The Eliminate Dengue *Wolbachia* programme is a good example of a programme where ground staff who service several hundred BG-S traps serve as the public face of the programme (http://www.eliminatedengue.com/program).

Literature is available to guide the calculations of the required sample size, but depending on the precise purpose of surveillance the number of traps placed should be maximised, particularly where the ratio of released to wild males is being followed. In this case the use of a large number of inexpensive passive traps is most suitable, when this has been developed for males. The level of sampling which is possible will depend on the human resources available, and the number of households willing to participate. A threshold minimum number of traps required to collect meaningful data probably exists, however, and at low numbers a wide and representative distribution of traps is critical.

The optimal intensity of sampling cannot be determined in detail before surveillance has begun, and an idea of the population density and distribution has been gained. A good starting point would be to place a small number of traps (for example 30 BG-S traps in an area of 200-500 houses) distributed through the surveillance area to collect some initial data points upon which refined surveillance is based.

Several criteria must be met when selecting sites for trap placement:

- Householders should be willing to participate in the trapping programme, and to accept the placing and servicing of traps, which relies in part on the attitude and approach of the field workers
- A power supply should be available, if possible, depending on trap type, e.g. BG-S (where this is not available batteries may be used in place of a power supply)
- Direct exposure to sunlight and rainfall are avoided. Outdoor traps can be located in the shade or dark areas with high humidity e.g. under wash basins. Indoor sites in dark corners (if possible).
- The site does not have a high level of human activity and is not vulnerable to damage by domestic animals and small children
- Trap can be placed at ground level to 1 meter high
- Traps are visible, so that they act as a visual cue for mosquitoes to locate them, and labelled with their purpose and the advice 'Please Do Not Disturb', along with community engagement to minimise removal of traps by householders

Programme managers are expected to use their discretion on site selection and trap placement regimens, because some flexibility will be required in the field to meet all or some of the criteria outlined above. Unexpected factors may arise which affect the placement of traps, for example the presence of aggressive dogs or uncooperative householders may make a certain property unsuitable for inclusion.

When considering *Aedes* population surveillance in particular, the heterogeneity of the population distribution must be considered. Very different trap data can be collected from neighbouring properties. If traps are relocated, this may affect the representative character of the estimates obtained and it should be considered whether this is advisable. A common approach when a property is not available is to relocate the trap to an adjacent property.

An important factor in obtaining useful data from traps is the length of time between setting the traps and collecting samples or scoring the individuals caught. The precise purpose of the surveillance will be a factor in deciding this parameter. For example, if analysis of collected individuals is required, the length of time before collections are made should be shorter, particularly in tropical or humid conditions, where samples will deteriorate more rapidly. Where ants or other predatory organisms are present in the environment, samples must be protected, or the traps emptied more regularly. In addition, the trap type will be an important factor in collecting suitable samples. Some will be more destructive, and some more suited to preservation of samples, for example wet traps collecting adults in a preservative liquid for PCR analysis. To minimise labour requirements and to maximise the number of mosquitoes collected from a surveillance tool, the longer a trap can be left before collection the better, though this will be situation dependent and there is no single recommended optimum time. Where non-lethal ovitraps are employed, collections must be frequent enough to prevent the emergence of adults from the eggs collected. A positive relationship which has been established with the residents in the study area will be important, and careful preparation and discussion of the importance of the work beforehand will increase the support from householders and scope in which you will be able to work.

The following is a summary of the current gold standard approach to surveillance based on what is available for each contingency:

1. Monitoring and evaluation should be conducted using BG-S and ovitraps for *Aedes aegypti* and *Aedes albopictus*, and human landing catches may be used when there is no evidence of local transmission
2. Gravid traps to attract females, Shannon Dawn traps, and sticky resting and pit resting traps, alongside house aspiration can be useful for *Anopheles* surveillance, though further population monitoring tools need to be developed and validated for this genus
3. A draft methodology for evaluating population size is required
4. Use of UAVs, computerized data collection and electronic devices could be employed to unveil or reveal a better understanding of biological questions e.g behaviour or field orientation of sugar feeding mosquitoes

2.2.4. Experience from surveillance of other pest species

Guidelines and standards on trapping and surveillance fruit flies are widely available in the current literature (FAO/IAEA (2013) Trapping guidelines for area wide fruit fly programmes (http://www-naweb.iaea.org/nafa/ipc/public/Trapping-Manual-Final-sept13.pdf); ISPM 26 Appendix 1 (2006); Fruit fly trapping; Shelly T., Epsky N., Jang E.E., Reyes Flores J., Vargas R. (2014) Trapping and the Detection, Control and Regulation of Tephritid Fruit Flies); (FAO/IPPC standard).

For the most common species, specific lures (para-pheromones) for males and synthetic food lures are commercially available. Trapping procedures describing deployment of traps, density and inspection frequency have been standardized for fruit fly control programmes with different goals, such as permanent suppression, eradication, prevention or containment.

In the case of tsetse flies, trapping guidelines are available in the document Collection of Entomological Baseline Data for Tsetse Area-Wide Management Programmes by Leak S., Ejigu D. and Vreysen M., published by the Joint FAO/IAEA in 2008. Available trapping methods are based on a variety of sensory perceptions: odours such as cow urine, acetone and several phenol compounds, for long range attraction and visual cues for short range attraction (phthalogen blue induce attraction while black induce landing response). Different trap types and attractants combinations are recommended for different species of tsetse flies.

3. DEVELOPMENT OF MALE TRAPS AND SURVEILLANCE PROTOCOLS FOR MOSQUITO SIT PROGRAMMES

The success or failure of SIT approaches depend strongly on accurate initial information on the local insect population and can be cost/benefit optimized if precise survey of the population is available through real-time monitoring and the efficacy of intervention. While SIT is among the most environmentally friendly pest management solutions known to mankind, it requires significant investment - necessitating prolonged effort from large teams. Therefore negative field results can damage the reputation of SIT and should be avoided, especially in pilot trials. Consequently, if the information on the local male population is uncertain, releases are likely to require overdesign counting on worst case scenarios to remain on the safe side. Since the overwhelming majority of the total project cost of successful project is due to recurring operations, a fine-tuned feedback system that relies on trustworthy near real-time monitoring can be an initial investment of high value.

To establish a surveillance programme it is essential that a sound understanding of the biology, ecology and population dynamics of *Aedes* and *Anopheles* mosquitoes be known. The question of why do male and female mosquitoes disperse is instructive because without this knowledge a surveillance programme would be impossible to develop. For example, the following parameters are important:

- Post emergence dispersal
- Copulation driven dispersal
- Sugar feeding foraging and dispersal
- Swarming and dispersal
- Weather regulated dispersal- influenced by wind, rainfall, temperature and humidity
- Avoidance of insecticides and inhospitable areas

3.1.Changing needs for male surveillance during programme phases

The needs for monitoring mosquito populations change during the SIT programme phases. To distinguish these, the phases we are considering are *the planning and technology development* phases and *the operational phase*.

3.1.1. The planning and technology development phase

During this phase, the size of the target site mosquito population needs to be determined so that the the facility to be built can be planned to produce at least enough mosquitoes to adequately overwhelm the wild population. Many population monitoring methods provide indices of relative population abundance, however all existing routine sampling methods (e.g. ovitraps, BG traps, human landing catches) require an external method to estimate the absolute populations size contemporaneously and thus 'calibrate' the sampling methods. The most direct of these methods is mark-release-recapture. Estimates of population size using genetic analysis (effective population size) are also possible but less direct.

To estimate maximum number of males in the population during this phase, it may be adequate to monitor only female populations since the sex ratio at emergence is normally 1:1 and males have been observed to have lower daily survival than females. Estimates of the absolute population size allow project planners to determine whether the level of sterile male production that is planned will match the target population size. Once the calibration by mark-release-recapture has been performed, routine sampling of either females or males can indicate the population trends and indirect estimates of the population size. If only females are routinely collected, calibration by mark-release-recapture must be performed by releasing marked females. This has been done commonly historically (Guerra et al., 2014), but it is becoming less acceptable. In cases where it is not permitted, male collections are necessary.

During this phase, male trapping methods suitable for field use are required to answer questions other than the target population size: How long do released males survive? How far do released males disperse? These require male trapping or some other collection method. A third important question regarding male performance, "Do released males mate competitively?" can usually be answered by experiments in semi-field structures where wild and sterile males compete for females, which are analysed for fertility of their offspring.

Two other pieces of information related to male performance need to be developed during the planning and technology development phase: male survival and dispersal. Both of these require some method of recovering (trapping or collecting) released males. These data demonstrate whether the methods for production, sterilization, transport and release are resulting in robust males that are likely to be effective for population reduction.

3.1.2. During the operational phase

After operations begin, capturing males provides an ongoing indicator of the overflooding ratio and the wild population size, because the number of sterile males released is known. Routine trapping is essentially a continuous mark-release-recapture activity during which sterile males are captured along with unmarked wild males. Unexpected changes in the numbers and ratios of male captures indicate operational issues that may need immediate resolution. While declining female abundance of disease vectors is the most important indicator of an SIT programme's success, the delay between male release and changes in female abundance do not allow the immediate feedback to production and release activities that male monitoring provides.

3.2. Operational technical requirements

Key characteristics of surveillance systems for population monitoring and evaluation of suppression activities are common to both *Anopheles* and *Aedes*. While it is unlikely that all can be met in one device, development of trapping and surveillance methods should keep in mind these outcomes.

3.2.1. Requirements of traps used for SIT surveillance programs:

- Species specific, particularly during the operational phase
- Sensitive, especially for males but which also collects females which can be used to estimate population suppression
- Cost effective – more complex, expensive traps for research activities, while low cost passive traps for longer term routine surveillance, and ovitraps for measuring induced sterility in *Aedes*
- Versatile for a broad range of species if used during the development phase
- Sensitive (captures proportional to population size), when target species alone is being monitored
- Preserve collected mosquitoes for further analysis where required (e.g. mark-release-recapture or species ID)
- Good quality and durable
- Light weight, easy to transport, set and collect
- Low in man-power demand
- Acceptable to householders and wider community.

More specifically, considering the characteristics of the ideal trapping tool described above, in order to develop improved surveillance programmes for both *Aedes* and *Anopheles* species, the following is a list of technical advancements which should be considered priorities for development:

a) Efficient male and female traps

b) UAV methodology of swarm monitoring

c) Better mark-release recapture modalities

d) Independent monitoring tools – automated surveillance and real time remote data collection

e) Means for quality control and validation of trap effectiveness

Since quality control tests shall be performed in Seibersdorf, and in particular in field sites of operational SIT programmes in Member States as they progress, we believe that it is very important that the CRP participants have easy contact with these programmes.

3.3. Research required to inform the design process

Fundamental research in the following fields will be required to inform the development of improved trapping tools and surveillance programmes:

a) Basic male and female biology
b) Basic ecology e.g. resting sites of mosquitoes
c) Behavioural studies in laboratory and field
d) Develop a gold standard for male collections
e) Validation tools
f) Community engagement tools
g) Field trials should be rigorous with appropriate statistical approaches, e.g. use of Latin Square design for trap evaluation
h) Modelling tools.

3.4. Translational research required to inform the design process

Applied research is also required, to exploit knowledge of male biology to convert the results of basic research into prototype tools for improved surveillance:

- Develop use of acoustic lures in traps. Can sounds attract male mosquitoes? Which frequencies, distances etc. How can these be produced efficiently?
- Build on current knowledge on sugar feeding, response to sounds, light and other stimuli to enhance or make more efficient available devices. What fragrances attract male mosquitoes? These could be both host (*Aedes*) and/or plant fragrances.
- Which patterns and/or colors attract males? Over what distance and in which lighting conditions?
- What is the effect of humidity on attraction of males?
- Identify and exploit the properties of swarming mosquitoes. What characteristics define an *Anopheles* swarm marker?
- Capitalise on the mosquito response to light barriers, e.g. to drive adults towards a trap, or to enclose or selectively kill adults within a trap
- It is likely to be desirable to develop a passive trap that is comparably effective as a powered trap to collect male mosquitoes at a lower cost and level of complexity.
- In the longer term more complex solutions can be developed using some or all of the translational research described above, perhaps including new trap designs altogether, for example making use of a bladeless fan, and exploit a greater understanding of flight and orientation behaviours of *Aedes* and *Anopheles* adults
- Develop tools to connect survey results to programme planning, execution and modelling

3.5. Areas for technical development

3.5.1. Modification of existing traps for male detection

Most attention paid to traps and other collection methods for studies of mosquito vectors has focussed on female surveillance but no methods have been developed specifically for collecting males, except the netting of males seeking mates near hosts (*Aedes*) or swarms (*Anopheles*).

Resting shelters take advantage of the behaviour common to males and females of seeking cool, humid and shady places, so further investigations of various configurations of resting shelters, specifically for their ability to attract males, are warranted. These might include the addition of humidity sources, or efforts to increase attractiveness; existing traps could be modified by either changing their visual cues or by adding odours or sound. Traps my require two kinds of attractants, for example a visual cue for longer range attraction and sound or odour for short range attraction, an approach used for both fruit fly and tsetse trapping. It is well established that mosquitoes similarly utilize different cues at long and short range.

Beside mating and resting cues, three additional attractive elements might be explored in the modification or design of new traps. The first is floral, fruit or other artificial fragrances that might attract males. It is well-established that both sexes feed on sugar though the necessity of this is more convincing for males that cannot obtain energy from blood. Several studies have shown that mixtures of e.g. fruit juice, sugar, wine are attractive to mosquitoes. To our knowledge, these have been utilized for control trials but not in trapping for surveillance. A variety of natural and purified chemical attractants have been identified and are available 'off the shelf' for testing in male-trapping devices.

Secondly, many species of mosquitoes, including *Aedes aegypti*, are attracted to sound at specific frequencies. Several demonstrations of field trapping (see references by T. Ikeshoji, Appendix III) of males, and serendipitous observations of male attraction to electronic devices, illustrate the value of sound as a readily accessible entrée to investigations of its use for male trapping.

Finally, analogous with many agricultural pests whose pheromones have been exploited for monitoring and control, it is also possible that pheromones are emitted from males that swarm which might attract other males or that females seeking mates emit attractive chemicals. Both of these possibilities could be explored by analysis of volatiles combined with bioassays.

Attractive chemicals, sounds and improved resting shelters are all compatible with existing trap designs and could be economical modifications of existing traps. All of these are potentially readily developed innovations for male trapping.

3.5.2. Emerging technology for mosquito detection

We recommend concentrating these activities on emerging technologies that can enable accurate, cost effective, and robust monitoring of the necessary variables to enable the SIT feedback loop to operate at a close to optimal cost-benefit point. Some of these technologies are being developed within a project, 'What bugs mosquitoes?' funded by the Bill and Melinda Gates Foundation.

All aspects of the sterile male release based vector control strategies can be affected by emerging technologies from production, through release, to monitoring. We will discuss some of the aspects, the unmet needs, technological opportunities, and research requirements.

Monitoring of wild-type and sterile insect populations in real time, especially for male *Anopheles*, traditionally had been a challenge both from the human labour and technical viewpoints. Unsupervised intelligent networked traps that can automatically identify gender, species, and fitness real-time will be a game changer. Highly detailed large data from intelligent traps will not only enable lower cost and successful SIT operations, but shall also provide new insights into the behaviour of disease vectors and agriculture pests worldwide.

Considering ongoing mass rearing/monitoring operations, a 400$/trap initial investment in intelligent trap upgrades can be offset in about one year assuming e.g. Australian salaries, albeit it can take multiple years in countries with lower wages. Since the direct cost of hardware for intelligent traps can be well below US$100, the cost point is promising. Certainly the technology today allows the realization of sophisticated intelligent traps. If the initial software and development is financed properly, such as research grants in academia, that it does not need to be offset in trap-upgrade sales then a sustainable sales price can be achieved ensuring long term progress and availability.

Traps integrated with machine vision and internet connectivity shall enable the precise identification of the target species, measure individual size, record fluorescent markers, determine gender, and test fitness. The availability of detailed information in near-real-time will enable operators to fine-tune the monitoring, intervention, and global health efforts.

Next generation intelligent traps and their enhancements will happen in the coming five years. They are enabled now by powerful embedded computers, high resolution wide bandwidth imaging devices, and broadband internet connection available in rural settings.

3.5.2.1.Computing

Affordable embedded computers are available in the US$/Gigaflop range enabling full featured computing modules in the <US$50 range, certainly sufficient to do all computations a trap might require and preparing dense data content that can be uploaded to remote high performance computing clusters for future detailed analysis. The computing power also enables local real-time computing for prompt local actions, such as selective collecting or exterminating of insects. Using general purpose computing devices also enables long-term upgrade-ability that ensures that intelligent traps remain on the cutting edge for the duration of SIT projects. Smartphones provide a powerful platform with integrated camera and networking ability and the integrated wifi and mobile connection enable versatile broadband connections. The seamless integration provided by smartphones mitigates risk and makes them prime candidates for trap integration, albeit their programming requires specialized expertise and the proprietary hardware/firmware/software can pose challenges, decrease flexibility, and limits upgrade-ability. General purpose hardware, such as ARM processor based Linux boards, requires significant hardware integration effort, but provides extreme flexibility, standard programming environment, and long-term upgradability.

3.5.2.2.Cameras

Ready to integrate megapixel digital cameras that also have NIR sensitivity are available in the <US$10 range and many smartphone feature 5-10 megapixel cameras. These cost-

effective imaging devices are capable of collecting images that enable in-depth analysis on remote computing clusters and basic real-time image analysis locally.

3.5.2.3.Network

Mobile internet is widely available in the developing world and high speed satellite internet is available widely. Cost-effective networking is not a problem at the scale of the normal operations, e.g. HughesNet is available at extremely high speeds at <US$50/month.

3.5.2.4.Power

Solar power is sufficient to supply the few watts of power embedded devices require and any local power system that is sufficient to charge cell phones can easily serve the intelligent trap's computing core.

3.5.2.5.Software

The cornerstone of machine vision systems is the software, and software needs to be fast and efficient in near-real time systems. Since the local computing power in intelligent traps is limited, it is expected that only data collection and basic image analysis shall be done on the local embedded computer and everything else will be done on remote computing clusters. Since general access cluster computing is affordable the risk due to slow algorithms is mitigated through the use of internet. Data loss due to damage or theft is also avoided through immediate transfer of data through the internet. Nevertheless much development of software is necessary by experts of insect imaging and machine vision. Software development is the current critical bottleneck on the way to useful intelligent traps.

Often the physical collection of specimens are not necessary therefore flow-through devices can be used instead of traps as the image based monitoring can provide all the information required by the projects. This can further decrease the need for regular human maintenance and allows the trap to be placed in less accessible locations decreasing the risk of damage, theft, or accidental interference.

Sometimes the selective killing of insects (e.g. of wild type mosquitoes) is desirable. The high resolution imaging and local CPU power enable immediate action that should enable immediate and power efficient extermination or collecting of a subset of insects flowing through the monitoring device while providing safe passage for the rest of the insects entering.

Often times male mosquitoes circle, but do not enter traps. *Anopheles* particularly, often swarms at predictable locations. Visual surveys around intelligent traps and swarming sites with similar hardware and software to the intelligent traps can collect priceless information about insects approaching the traps, humans, households, and swarming sites. This information was not available in the past and could open new avenues for surveillance e.g. to investigate the ever-elusive males and their mating interactions.

Monitoring and selective counting of wild type and sterile male populations is possible with the visual systems. For example human raised mosquitoes are very well fed therefore distinguishable from wild-type by size - size is fairly easy to measure from images therefore providing a cost effective automatic survey of the sterile/wild-type ratio on field. Fluorescent dies can also be easily identified by the imaging systems. Distinguishing in real-time between sterile and wild-type insects allows for the selective extermination of wild type and re-releasing of the sterile that in-turn enables extensive precision surveys where non-selective trapping could interfere with the sterile population.

Swarm location and swarm size detection can allow insight into the size of local male mosquito population that is inaccessible to traps. Real time localization and characterization of swarms should be possible through wide area acoustic surveys and possibly UAVs. The cost of such an approach is unknown and requires further research, however the benefit of a successful approach can be significant.

Larvae collection and identification might be possible through optical means by imaging the water surface of breeding sights. While there should be no technical barrier to this approach the practical limitations and precision should be determined through future experimentation.

Mathematical models and Monte-Carlo simulations can enhance the efficacy and precision of monitoring through trap placement advice and extrapolation of sparse measurements. However accurate models require significant development work, validation, and local dependent tuning. Therefore the near-term utility of mathematical simulations remains to be proven.

(Related research need: Method to mark released males – dye as in Mediterranean fruit fly programmes, stable isotopes (only for small scale experiments due to cost), and wing length may be useful to identify released males).

4. RECOMENDATIONS TO MEMBER STATES

1. Encourage applications by suitable researchers to participate in the proposed CRP on "Handling, transport, release and monitoring of mosquitoes"

2. For the surveillance of *Aedes* species, programmes should focus on existing tools, and validate and optimize their use locally

3. For *Anopheles* surveillance, efforts should focus on the development of new tools which are able to collect adults in meaningful numbers

4. Standard protocols for designing programmes of surveillance, at all stages of the SIT programme, should be developed at each locale

5. Protocols should also be developed to determine effective methods for population quantification, e.g. trap type, placement, how long to leave traps, sampling size, and the type of surveillance to employ at different stages of the programme.

5. RECOMMENDATIONS TO THE IAEA

1. Initiate a CRP that includes the development of technologies for monitoring of wild and sterile mosquito populations, and invite suitable participants to join

2. Strengthen relationships with academic and industrial partners, developing collaborations where possible, and finding means to provide larger research grants where necessary for the development of expensive technology by commercial partners

3. Identify sources of funding to support procurement for private sector partners, for example by supporting grant applications by private sector partners to develop new trapping methods

4. Recruit suitable collaborators with good scientific and programmatic experience who can validate the proposed surveillance solutions in a programmatic environment

5. Support research to address the fundamental and applied research requirements outlined in Sections 3.3 and 3.4 to help engineers to provide suitable technologies

6. Provide more support to the Joint FAO/IAEA Insect Pest Control Laboratory, Seibersdorf to assist in their efforts to answer the large number of research questions remaining to support mosquito surveillance activities

7. Programme frequent communication exchange between CRP participants working on engineering solutions and Agency technical staff; this is a key issue for increasing the likelihood of finding a realistic solution.

Support should be provided to Member States in the following forms to assist in the development and evaluation of surveillance activities:

1. Development of guidelines for design of optimal surveillance activities, staged for different phases of and SIT programme

2. Development of means to mark male adults prior to release

3. Fellowships, Scientific Visits and Expert Missions to support implementation of effective surveillance activities in Member States

4. Purchasing of equipment and shipping of materials, both existing tools and new solutions as they are developed

5. Support in programme planning and field operations, including development of Standard Operating Procedures which can be adapted to local situations

6. POTENTIAL PARTNERS FOR RESEARCH, EQUIPMENT DEVELOPMENT/MANUFACTURE AND FIELD TESTING

1. All participants of this meeting

2. All participants in the Consultants meeting on handling, transport and release

3. Louis-Clement Gouagna - IRD - louis-clement.gouagna@ird.fr – has done research into sugar source preference in *Anopheles arabiensis*

4. Jason H Richardson - US Army - jason.h.richardson.mil@mail.mil – a medical entomologist in the US military, specialises in developing new tools to prevent mosquito-borne diseases, focus on malaria, dengue fever, and leishmaniasis

5. (Ronald) Jason Pitts - Vanderbilt - j.pitts@vanderbilt.edu – specialises in the chemical ecology and sensory ecology of disease vector insects

6. L J Zwiebel - Vanderbilt - l.zweibel@vanderbilt.edu – the comprehensive study of olfaction and olfactory-based behaviours in malaria and other disease vector mosquitoes (mainly *A. gambiae*)

7. Phil Lounibos - University of Florida- lounibos@ufl.edu - core focus is insect ecology and behavior, especially as applied to mosquito vectors of human diseases, such as malaria and dengue

8. Dana Focks - John W Hock company dafocks@phhp.ufl.edu - Developing validated assessments of the potential consequences of climate change and control strategies for dengue, malaria, schistosomiasis, and Lyme disease

9. Bioquip – bqinfo@bioquip.com (general info email) - Equipment, Supplies and Books For Entomology and Related Sciences

10. Dan Kline, USDA, Gainesville, Florida, USA - Dan.Kline@ars.usda.gov - *Aedes albopictus*, surveillance and trapping

11. Gunter Muller- Israel – guntercmuller@hotmail.com – *Anopheles* - Sugar feeding

12. Abdoulaye Diabate - a_diabate@hotmail.com – mating behaviour of *A. gambiae* and male mosquito biology

13. Gabriella Gibson – University of Greenwich - g.gibson@greenwich.ac.uk – Anopheles, mainly *A. gambiae* and to elucidate how disease-transmitting insects use their sensory systems (vision, hearing, smell, taste and touch)

14. Lauren Cator, Imperial College London - l.cator@imperial.ac.uk – improve understanding of mosquito behaviour - feeding behaviors of infected mosquitoes and mosquito mating behavior in aerial swarms.

15. Willem Takken - Wageningen, The Netherlands - willem.takken@wur.nl – biological control, chemical ecology within *Anopheles* mainly

16. Derek Charlwood – London School of Hygiene and Tropical Medicine, Liverpool School of Tropical Medicine - jdcharlwood@gmail.com – malaria vectors, trapping, insecticides

17. Tom Burkot – Australian Institute of Tropical Health & Medicine - tom.burkot@jcu.edu.au – improving how malaria vectors are controlled and monitored, Solomon Islands

18. Herve Bossin - Institut Louis Malardé, French Polynesia – hbossin@ilm.pf – *Aedes*, Wolbachia

19. Innovative Vector Control Consortium – Liverpool School of Tropical Medicine - info@ivcc.com -

20. Intellectual Ventures Laboratory - press@intven.com (press contact email – no general email, comments to be submitted via the website online form). Company focuses on the very beginning part of inventions (listed on website – artificial diet and malaria diagnostics)

21. Bart Knols - In2Care – The Netherlands - bart@in2care.org -

22. Donald Barnard – USDA - don.barnard@ars.usda.gov - Methods for estimating adult mosquito density, vector insect surveillance

23. Alvaro Eiras – Universidade Federal de Minas Gerais, Brazil - alvaro@icb.ufmg.br - Aedes, trapping

24. Greg Devine - QIMR Berghofer, Medical Research Institute, Brisbane, Australia - Greg.Devine@qimrberghofer.edu.au - *Aedes (albopictus*), Wolbachia

25. Alassandra Della Tore – Sapienza University of Rome - ale.dellatorre@uniromal.it – *Anopheles,* trapping methods, some *Aedes* work too

26. Romeo Bellini- Centro Agricoltura Ambiente "Giorgio Nicoli" - Italy - rbellini@caa.it – biological control of mosquitoes, *Aedes*

27. Woodbridge Foster- - The Ohio State University - foster.13@osu.edu - behavior, physiology, and behavioral ecology of arthropod vectors of vertebrate pathogens, emphasis on the role of plant sugar in mosquito biology and vectorial capacity

28. John Beier – University of Miami - jbeier@med.miami.edu - ecology and control of vector-borne diseases, including malaria, dengue, arboviruses, and leishmaniasis, malaria epidemiology and control in Latin America and methods for malaria vector control in Africa

29. Imre Bartos – Columbia University – ibartos@phys.columbia.edu – physics of *Anopheline* mosquito eyes

30. Rui-De Xue – Anastasia Mosquito Control District, Florida - xueamcd@yahoo.com – *Aedes,* developing pest management strategies in Florida

31. W. Abeywickreme – University of Kelaniya, Sri Lanka - wabeyewickreme@yahoo.com - Parasitological and Molecular biological aspects of vector borne Disease pathogens and their vectors

32. Jonathan Kayondo – Uganda Virus Reseach Institute - jkayondo@nd.edu – genetic and population structure – *Anopheles,*

33. James Mutunga – ICIPE - International Centre of Insect Physiology and Ecology, Kenya - jmutunga@vt.edu (can't find a more up to date one for him) – *A.gambiae*

34. Mamadou Coulibaly – Malaria Research & Training Centre, Mali – coulibaly7@gmail.com – *Anopheles,* mainly *gambiae*

35. Basil Brooke – National Institute for Communicable Diseases, South Africa – basilb@nicd.ac.za – insecticide resistance in African malaria vectors

36. Lizette Koekomoer – National Institute for Communicable Diseases, South Africa - lizettek@nicd.ac.za - characterization of metabolic based insecticide resistance mechanisms in malaria vector mosquitoes

37. William (Bill) Hawley – Centres for Disease Control & Intervention (CDC) – whawley@unicef.org - malaria epidemiology and mosquito biology

38. Roger Nasci – CDC – rsn0@cdc.org - arbovirus ecology, vector control and the design and implementation of arbovirus surveillance and response programmes

39. Frank Collins – University of Notre Dame, Indiana – Frank@nd.edu - genome level studies of arthropod vectors of human pathogens and field and laboratory research on malaria vectors, *Anopheles gambiae*

40. Dan Strickman – Senior Program Officer for Vector Control (Bill & Melinda Gates Foundation) USDA – daniel.strickman@ars.usda.gov – insecticides, *Aegypti*

41. Wellcome Trust – (general enquiries) contact@wellcome.ac.uk – biomedical research charity

42. Adriana Costero-Saint Denis – National Institute of Allergy and Infectious Diseases (NIAID) - acostero@niaid.nih.gov – *Aegypti*, vector control

43. Biotechnology Industry Research Assistance Council (BIRAC) – India - birac.dbt@nic.in - offers funding opportunities to small organizations involved in innovation in the biotech industry

44. Amy Morrison – University of California – aegypti@terra.com.peru *Aedes aegypti* (dengue)

45. Thomas W Scott - University of California - twscott@ucdavis.edu – *Aedes aegypti* (dengue/west nile), some malaria work

46. Nicole Achee – University of Notre Dame, Indiana - nachee@nd.edu – *Anopheles,* evaluation of vector ecology, habitat management and adult control strategies, disease risk modeling using GIS and remote sensing technologies

47. Nigel Beebe – University of Queensland & *Commonwealth Scientific and Industrial Research Organisation* (CSIRO) - n.beebe@uq.edu.au - mainly *Anopheles,* some *Culex*

48. Fred Gould – North Carolina State University – fred_gould@ncsu.edu – ecology and genetics of insect pests

49. Nick Hamon - Innovative Vector Control Consortium – Liverpool School of Tropical Medicine - nick.hamon@ivcc.com – primary current focus is malaria eradication

50. Pablo Manrique-Saide - Universidad Autónoma de Yucatán**, Mexico –** manrique@sureste.com - work includes the evaluation of entomological-infestation measures and control tools for *Aegypti*

51. Corey Brelsfoard – St Catherine College, Kentucky - coreybrelsfoard@sccky.edu - Lymphatic filariasis, Wolbachia

52. Luciano Andrade Moreira – Fiocruz – luciano@cpqrr.fiocruz.br - malaria, wolbachia,

53. Stephen Higgs – Kansas State University – shiggs@k-state.edu - *Aedes*

54. Anthony James – University of California – aajames@uci.edu - Molecular biology of insect vectors of disease, genetics of vector competence, malaria, dengue fever

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8. APPENDIX I: AGENDA

TECHNICAL MEETING ON "MOSQUITO MALE TRAPPING METHODS TO MONITOR THE EFFICACY OF SIT PROGRAMMES IN THE FIELD"

16-20 February 2015, Vienna, Austria

Vienna International Centre (IAEA Headquarters), Rooms B1144 and B1025

MONDAY, 16 FEBRUARY 2015. Room B1144

08:00 – 09:00 Identification and registration at VIC Gate (next to subway station U1)

09:00 – 09:10 **Sulafa Karar:** Welcome remarks

09:10 – 09:15 **Jorge Hendrichs:** Welcome statements and goals of the meeting.

09:15 – 09:20 **Rosemary Lees:** Agenda and administrative issues.

09:20 – 10:00 **Rosemary Lees:** Overview of current mosquito SIT programmes and related activities under the Joint FAO/IAEA Division of Nuclear Techniques in Food and Agriculture, and the need of Member States for more effective trapping methods for wild and sterile males.

COFFEE BREAK

SESSION I: Presentations by Consultants

10:30 – 11:30 **Dave Chadee:** An overview of the different existing trapping methods already available for Aedes and Anopheles and ongoing activities in Trinidad & Tobago.

11:30 – 12:30 **Mark Benedict**: Mosquito surveillance anticipating genetic control: exploitable behaviours from previous studies.

LUNCH

13:30 – 14:30 **Scott Ritchie:** Population replacement pilot trials and other field activities in Australia, and the surveillance systems which are used to monitor efficacy.

14:30 – 15:30 **Roberto Barrera:** Experiences of mosquito trapping in the field, Puerto Rico

COFFEE BREAK

15:45 – 17:00 Discussion

TUESDAY, 17 FEBRUARY 2015. Room B1025

SESSION II: Presentations by Consultants II

8:30 – 9:30	**Martin Geier:** Commercially available technology for trapping male mosquitoes, and the development of new techniques.
9.30-10.30	**Szabolcs Marka:** 'What bugs mosquitoes?' - new complementary approaches within a project funded by the Bill and Melinda Gates Foundation.

COFFEE BREAK

SESSION III: Requirements for an optimal surveillance systems.

11.00-11.30	**Rosemary Lees:** Requirements for a surveillance system enabling the monitoring of suppression programmes (via male-specific traps) to measure male quality and programme progress and to allow adjustment to operational activities in IAEA Member States
11.30-12.00	**Rafael Argilés:** Development of surveillance systems for insect suppression trials: Experiences from fruit fly and tsetse.
12.00-12.30	Discussion

LUNCH

SESSION IV: General Discussion. Room B1144

13:30 – 15:00	Identification of key characteristics of surveillance systems for population monitoring and evaluation of suppression activities.

COFFEE BREAK

15:30 – 17:00	Identification of development or research needs still to be addressed in terms of surveillance techniques, from a biological point of view.

WEDNESDAY, 18 FEBRUARY 2015. Room B1144

SESSION V: General Discussion (Cont.)

8:30 – 9:30 Current status of technology available for male mosquito trapping – including collection from swarms, passive trapping and active collection methods.

9.30-10.00 Identification of gaps and research needs still to be addressed in terms of trapping technology.

COFFEE BREAK

SESSION VI: Preparation of report, developing Recommendations for the Member States

10:30 – 12:30 Discussion and preparation of an outline for a recommended surveillance system, or situation specific systems, for Member States with operational mosquito SIT programmes.

LUNCH

13:30 – 15:00 Identification of the most suitable currently available technologies for each contingency.

COFFEE BREAK

15:30 – 17:00 Preparation of a statement of development and research needs, including specifications for optimal tools for trapping or otherwise collecting male mosquitoes.

THURSDAY, 19 FEBRUARY 2015. Room B1144

SESSION VII: Preparation of report, developing Recommendations for the Member States (Cont.)

8:30 – 10.00 Preparation of a list of suitable researchers who could help to address development and research needs.

10.00 – 10:30 Discussion and preparation of a draft methodology for evaluating and population monitoring tools, including validation of newly developed methods.

COFFEE BREAK

11:00 – 12:30 Discussion and preparation of a draft methodology for evaluating and population monitoring tools, including validation of newly developed methods. (Cont.)

LUNCH

SESSION VIII: Preparation of report, developing Recommendations for the IAEA

13:30 – 15:00 Discussion of the support that could be offered by the Agency to the Member States in developing and evaluating monitoring tools.

COFFEE BREAK

15:30 – 17:00 Preparation of Consultants' Recommendations to the IAEA

FRIDAY, 20 FEBRUARY 2015. Room B1144

SESSION IV: Finalisation of Consultants' Meeting Report

8:30 – 10:00 Reviewing outcome of Discussions and Recommendations.

COFFEE BREAK

10:30 – 12:00 Compilation of Consultants' Meeting Report

LUNCH

13:00 – 15:00 Group review of final meeting report.

COFFEE BREAK

15:30 – 17:00 Group review of final meeting report and brief presentation of outcome and recommendations.

9. APPENDIX II: LIST OF PARTICIPANTS

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10. APPENDIX III: REFERENCES ON SOUND AND SUGAR ATTRACTION

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